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CLIMATIC CYCLES AND EVOLUTION*

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[With separate map, Pl. V, facing p. 312.]

Introduction

It has always been admitted that climate is one of the chief factors in determining evolution. That great changes have occurred in past climates has been accepted by geologists since the dawn of the glacial controversy, if not earlier. It is only of late, however, that the possibility of important changes in recent and historic times has been carefully investigated, by Huntington, Penck, J. W. Gregory, and others.

It is the purpose of this paper to show that there have been recurring cycles of such climatic change, cycles that have exercised perhaps paramount influence on the evolution of life.

Two cycles seem to be shown in the biological and geological record. The minor cycle recurs every 200,000 years or thereabouts and has determined the duration of the four Pleistocene ice ages and also the development and migrations of the four main races of man. The major cycle is about 100,000,000 years long, and we have a record of three such major cycles since the dawn of the Cambrian Age. The minor cycles are superimposed on the major cycles in such a fashion that in each major cycle, after long ages of fairly uniform climate throughout the world, there appears a zonal arrangement of climates. This culminates at the four great ice epochs, that is in late Proterozoic, Devonian, Permian, and late Tertiary times.

The gradual change of climate through late Tertiary times is first described as it has affected Australia. This constitutes Part I of the paper. Then the effect of climate on man's ethnological characters is briefly dis-

* All the footnote references, except 2, 5, 6, 7, 24, 26, 35, 37, 38, 40, 41, 47, have been supplied editorially. For these the author is therefore of course not responsible. Nor was it possible to send him proofs of the article for revision—EDIT. NOTE.

cussed, and reasons are given for ignoring color as a major factor in race classification. The cephalic index and the hair, and to a lesser degree the culture of a race, are used as criteria.

A map of the world giving these characters for the primitive tribes (Pl. V) clearly indicates, as Matthew suggests,[1] that the biological center is in Asia and that all the races have migrated thence as a result of climatic thrusts. These latter were chiefly glacial at first and due to arid conditions later. Incidentally the "yellow" race is shown to have developed later than the "white."

Carrying the investigation back into earlier ages I find a similar sequence of climate for temperate regions. The four major ice ages are correlated with the striking breaks in the biological succession and with the periods of great mountain building. Evidence is given supporting the periodicity of these changes and indicating that a powerful weapon is thus placed in the hand of the geologist and biologist.

The time scale is then considered, especially in connection with radioactive experiments, and it is shown that to a certain extent it supports the cyclic hypothesis and enables us to fix absolute values for the major and minor periodic cycles.

Some suggestions as to the causes of these major and minor cycles are made. I especially wish to state, however, that, whether these suggestions be substantiated later or not, the earlier portions of the paper dealing with the periodicity of the phenomena will not be materially affected.

Part I

Late Paleoclimatology in Australia

For many years attention has been concentrated on the changes in temperature in past ages; but little has been written on the much more important feature—from the point of view of civilization—of rainfall.

The Rain Belt

In a model devised in 1912 (the solar-control model[2]) I was able to demonstrate how remarkably the continent of Australia lent itself to problems of climatology. The swing of the sun from tropic to tropic is followed by the swing of the isotherms. The latter reacts on the pressures, and the rains follow later, there being a lag of about five weeks.

From the present point of view it is important to note that the isohyets (rainfall) agree with the isotherms very remarkably. Moreover it is easy

[1] W. D. Matthew: Climate and Evolution, *Annals New York Acad. of Sci.*, Vol. 24, 1914, pp. 171-318; reference on p. 209.

[2] Griffith Taylor: The Australian Environment (Especially as Controlled by Rainfall), *Commonwealth of Australia Advisory Council of Science and Industry Memoir No. 1*, Melbourne, 1918; model inside front cover.

to plot the "center of aridity" month by month and relate it to the path of the sun and of the isotherms. This is shown in Figures 1 and 2. All the localities in Figure 1 are near longitude 135° E., and they show that the center of aridity moves north and south with the sun, but about four or five weeks later.

If we compare this belt of maximum aridity with the temperature, it is found to agree very closely with the isotherm of 75° F. In January this isotherm passes just north of the Great Australian Bight through Tarcoola (see Figs. 1 and 3). In April it passes between Oodnadatta and Daly Waters. In July it goes through Pine Creek. In fact it practically coincides with the driest place in each month, as the maps in Figure 2 demonstrate.

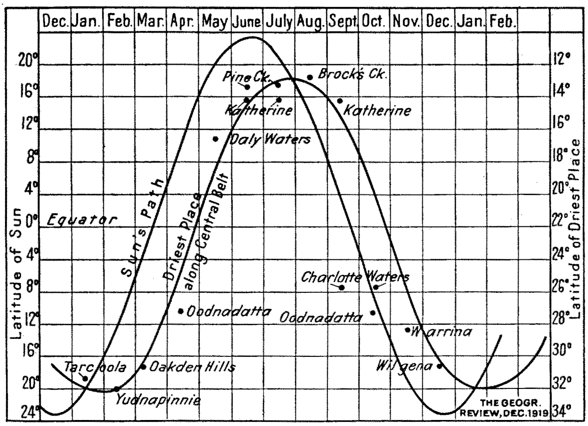

Fig. 1—Diagram showing the relation of the sun's march between the tropics to the march of the rain belt, illustrating the movement of the center of aridity across Australia. The driest spot in each month is used as index. (After Fig. 2 of the author's "The Australian Environment, Especially as Controlled by Rainfall," *Commonwealth of Australia Advisory Council of Science and Industry Memoir No. 1*, 1918.)

In a similar way the rain belts move *between* definite isotherms in Australia. There is no complication due to mountains or large gulfs; in fact Dame Nature has placed Australia like a blackboard on which fundamental climatic problems may be investigated.

The southern boundary of the tropical low-pressure rain belt (2-inch isohyet) agrees fairly well with the isotherm for 85° (see Fig. 2b). This isohyet defines the really heavy rains of the tropics, though of course there is some tropical rain south of the latitude concerned. The consequent hot moist climate only affects the continent for the three summer months in the tropics.

At this period (summer) central Australia has a hot arid climate, and the southern coast lands a cool arid climate. (In this discussion we are ignoring the east coast, where other factors affect the climate.) Only in Tasmania is the cool moist climate—which is that most favorable to civilized life—benefiting the land.

At the equinox (autumn, see Fig. 2c) the belts have moved north with the sun. The center of aridity (and the 75° isotherm) is now almost on the tropic. Tropical Australia is experiencing hot arid conditions, the central belt is cool and arid, the southern coast is cool and moist.

In winter the center of aridity runs through the northern coast lands

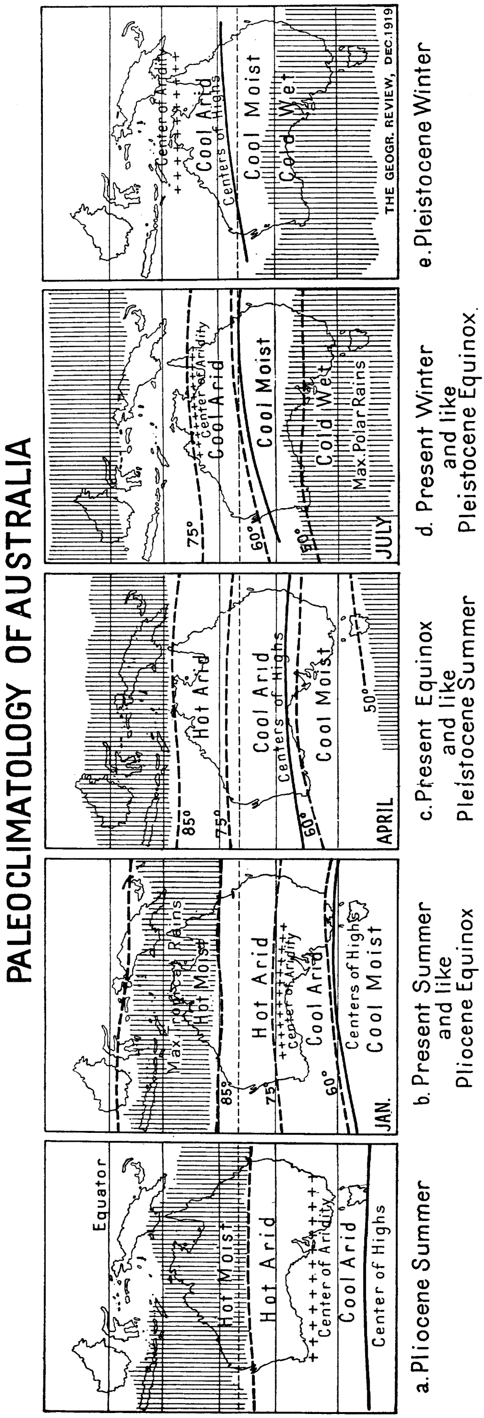

FIG. 2 (a to e)—Five maps showing the seasonal rain belts, Pliocene to present, in Australia. (Note—The Center of Aridity is lacking in Fig. 2c. It should lie just south of the 75° isotherm.)

(Fig. 2d), tropical Australia is largely cool and arid, the southern coast lands are cold and wet.

The Rain Belt in Pleistocene Times

Now suppose that the isotherms were all moved to the north, as would occur if the temperature of these latitudes fell, say, 5°; we should have the type of winter shown in Figure 2e. The center of aridity would coincide with Port Darwin (in winter). The whole of temperate Australia would be vastly improved in climate. Heavy rains would penetrate far north of their present limit. There would be a heavy snowfall on the Australian Alps, and glaciers would develop and reach down the valleys.

As we know, this is exactly what happened in Pleistocene times. Mt. Kosciusko shows many signs of glacial action, and a glacier three miles long and 1,000 feet thick extended down the valley of the Snowy River. At the present time only a few patches of snow exist through the summer on the sheltered eastern side of the range, though it reaches above 7,300 feet.

In Tasmania the glacial conditions were naturally more marked. I recently traced moraines which showed that in the National Park

(Mt. Field) a glacier about five miles long extended from the central range down the Broad River. Many fine cirques occur here, and also at Cradle Mountain and in the western mountains near Mt. Lyell.

As regards the lowlands in Australia there is overwhelming evidence of the happier conditions which obtained in Pleistocene times. Howchin

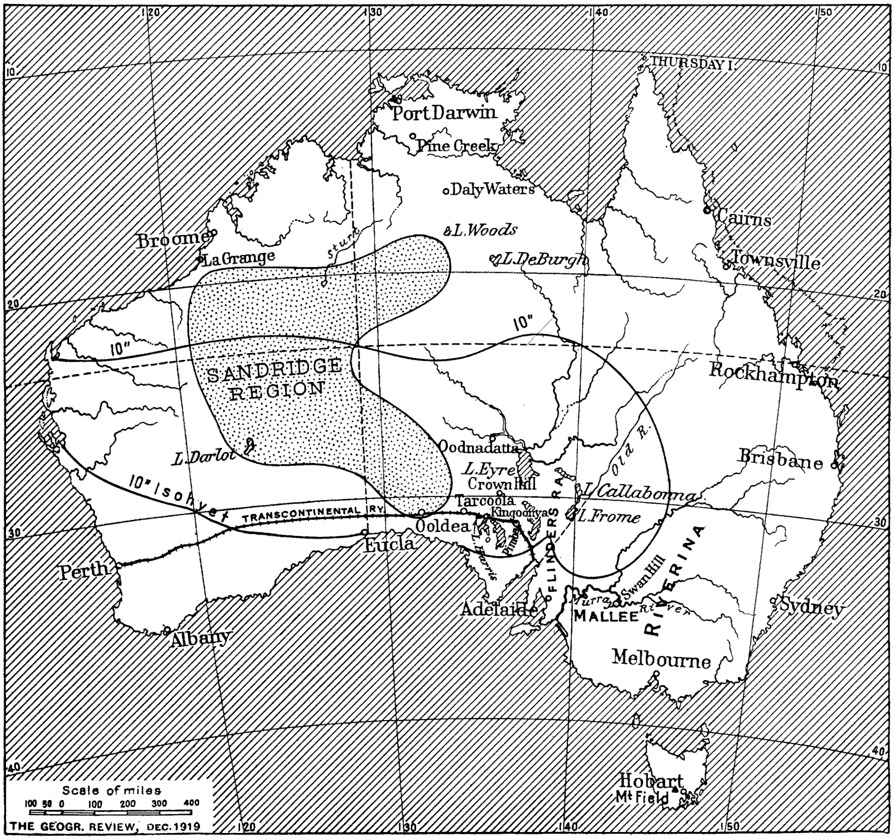

FIG. 3—Sketch map of Australia to illustrate Pleistocene conditions. Scale, 1:25,000,000.

has described[3] the course of large rivers which rivaled the present Murray and flowed south from Lake Eyre and Lake Frome.

The *Diprotodon*—a marsupial wombat as large as a rhinoceros—has been discovered in river and lake deposits throughout Australia. The most complete skeleton was obtained from the muds around Lake Callabonna (near Lake Frome; Fig. 3). But it is found near the arid Lake Darlot (Western Australia, latitude 28°) and all round Lake Eyre. It was a large herbivorous animal which certainly could not exist in a region which has only 7 inches of rain, as this region has at present. The present condition

[3] Walter Howchin: The Geography of South Australia, Including the Northern Territory, Historical Physical, Political, and Commercial, Melbourne, 1909, pp. 123-125.

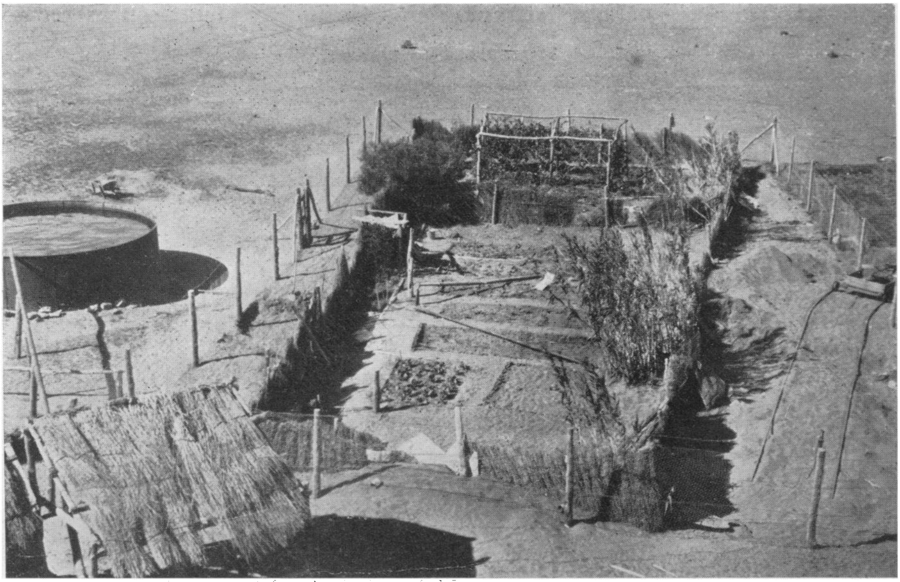

FIG. 4

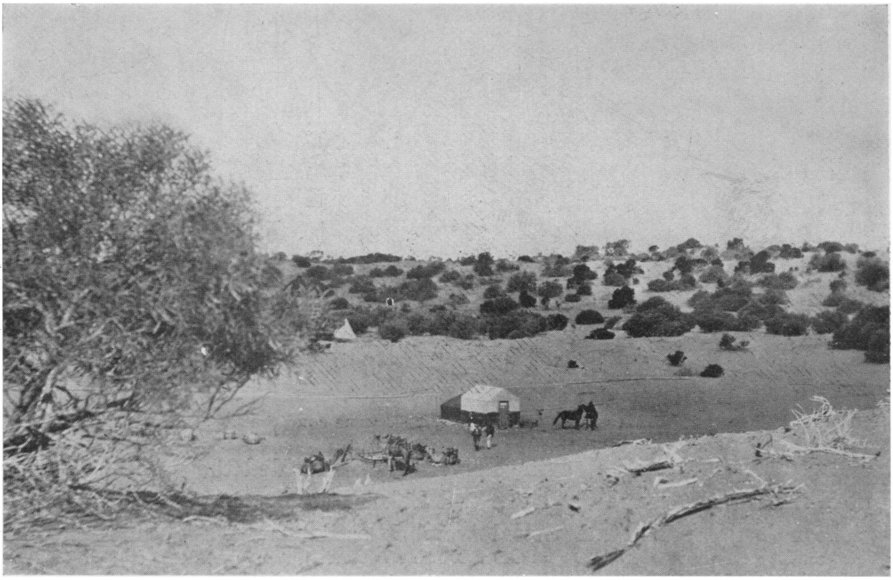

FIG. 5

FIG. 4—View of Crown Hill "oasis," South Australia, 70 miles southwest of Lake Eyre—for location, see map, Fig. 3. (Photo by the author, May 15, 1919.)

The view is taken from the windmill platform. The water is a Tertiary supply about 70 feet down. The iron tank supplies the "oasis." This is surrounded by wire netting to keep out rabbits, emus, and kangaroos. Inside this is a brushwood fence to keep out the sand drift. The latter has, however, invaded the enclosure on the north (near) side. A small tramway (of iron pipes) and an improvised wagon have been used to cart the sand to the lee side. Some vines and a few fruit trees at the back and cabbages in front can be made out. There is no permanent settlement between this "station" and the Indian Ocean at La Grange—one thousand miles to the northwest.

FIG. 5—View of Ooldea Well, South Australia, on the Transcontinental Railway, long. 132° E. (Photo by the author, May 10, 1919.)

The southern end of the great sand-ridge region in Australia, which extends to the Indian Ocean. Here is the chief water supply on the Transcontinental Railway between Kingoonya (S. A.) and West Australia. The camels indicate the native well found by Giles in 1876. The dunes are about 150 feet high and run roughly northwest. The pipe lines (seen back of the tent) carry water pumped to the railway four miles south. The vegetation is "mulga."

Fig. 6

Fig. 7

Fig. 6—View of Lake Harris, a typical playa near Kingoonya, South Australia, on the Transcontinental Railway, long. 135° E. (Photo by the author, May 12, 1919.)

The man is holding slabs of salt which have crystallized on twigs. The crust is one inch thick. In the background is a fine mirage (on the right). The trees are acacias ("wattle"). This photograph was taken a stone's throw from the next.

Fig. 7—View of Tomato Rocks, Lake Harris, South Australia. (Photo by the author, May 12, 1919.)

A small gulley in a low rocky outcrop of very hard porphyry, about half a mile across. Here there is only a 7-inch rainfall per year. The numerous potholes indicate much greater rainfall in the past. These red rocks lie on the shore of Lake Harris—see Fig. 6—and rise to about 80 feet above the general level.

of this region is shown in the photograph of the Crown Hill "oasis" (Fig. 4), 70 miles southwest of Lake Eyre.

The vast alluvials of the Riverina region and western New South Wales indicate a period when numerous large rivers flowed into the Tertiary sea of the lower Murray basin. On the Victorian side of the lower Murray is the Mallee country, largely consisting of huge sand dunes which have blocked the Wimmera River and other tributaries of the Murray. The dunes are also found at Ooldea on the Transcontinental Railway and stretch almost uninterruptedly to the northwest—right to the Indian Ocean. These dunes are slowly moving south in some cases, though they are usually covered with mulga (*Acacia*), tea tree (*Leptospermum*), and dwarf eucalypts (see the photograph of Ooldea Well, Fig. 5).

It is to be noted that in 1914 the Murray, large river as it is, ceased to flow below Swan Hill. The last similar occurrence is said to have been in 1839.

The land forms tell a similar tale. All through the salt-lake district of South Australia there are preserved mature valleys which are certainly not those which would be produced by a 7-inch rainfall. Near Pimba these are especially noticeable. The salt lakes in many cases seem to be old river valleys blocked by silts rather than typical playas cut out by wind erosion. In some cases terraces are visible on the valley walls, but no detailed investigations have yet been made. Many of the small rock outcrops contain short gullies with all the characters of a pluvial cycle. The potholes at Tomato Rocks (cut in hard feldspar-porphyry), only a stone's throw from the salt expanse of the playa Lake Harris, offer an interesting illustration of climatic change (see Figs. 6 and 7).

Thus there is no doubt of the gradual desiccation of southern Australia in Pleistocene times. It is not due to the growth of the Flinders Range, however (as Howchin has suggested[4]), but to the migration of the polar rain belt to the south in accord with a general warming of the whole earth since the ice ages.

Penck has suggested[5] a similar course of events in other continents, especially in Africa and North America. It is obvious that there should be some corresponding improvement on the equatorial sides of the desert, for in Pleistocene times the northern portion of Australia was much more arid throughout the year than now. This is indicated by the sequence of Figures 2c, 2d, and 2e. Perhaps this is the reason that a xerophilous vegetation is throughout so characteristic of the Australian tropics (except the extreme east coast), for the Malaysian flora has not yet been able to creep back along the coastal fringe, even where conditions are suitable for its existence.

Very little physiographic work has been done in the north. Possibly the

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[4] *Op. cit.*, p. 125.

[5] Albrecht Penck: The Shifting of the Climatic Belts, *Scottish Geogr. Mag.*, Vol. 30, 1914, pp. 281-293.

shallow depressions of Lake Woods and Lake De Burgh (lat. 18°-19°; cf. Fig. 3) are Pleistocene playas, which in the better rainfall of today are losing their desert characters. Sturt Creek runs into a "salt sea" (in latitude 20°) which is drinkable when it is full.[6] Here also the "sand ridges do not seem to be shifting perceptibly."[7]

In Pliocene Times

If we carry our survey farther back into the vistas of the past—as far as Pliocene times—we reach a period when all the evidence indicates a much warmer climate than obtains at present. Thus the Carolina flora flourished in France—which means that the temperature was about 5° warmer. Now 1° F. per degree of latitude is the normal horizontal temperature gradient. Hence the isotherms were displaced approximately about 5° of latitude (or 300 miles) toward the poles in Pliocene times.

I have indicated this in Figure 2a. We see that conditions in the south of Australia were probably much more arid than at present (Fig. 2c) in Pliocene summers. Possibly Australia south of the tropic received practically no rain all the year round, except along the eastern coast. We have not enough data to pursue this aspect further, but it is of interest to note that as far as we can tell all the present indications point to a temporary return to Pliocene conditions and to greater aridity in the south of Australia. Possibly the climatic belts will move south until the condition of Figure 2c (present) develops into that of Figure 2a (Pliocene).

Conclusions

In conclusion we see that an increase in the temperature of the middle latitudes—which chiefly interest the white man—causes a poleward movement of the equatorial low-pressure rain belt. This pushes the arid belt and the polar rain belts away from the equator, with tremendous results as regards the well-being of life in the belts affected.

This has been exemplified in Pliocene times, and we seem to be living in an era when the same trend obtains. This will benefit Canada and similar lands but will thwart development in Mediterranean lands and in southern Australia.

Conversely, if the general temperature decreases in our latitudes, the rain belts will move toward the equator. This occurred in Pleistocene times. Hence in the early historic age conditions were more favorable in regions like Babylon, Carthage, and Yucatan, where the climate is now too dry or too enervating. (Huntington has discussed this question[8] but does not seem to correlate their decadence with a "uni-directional" period of aridity so much as with a temporary arid "pulse.")

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[6] H. W. B. Talbot: Geological Observations in the Country Between Wiluna, Hall's Creek, and Tananu, *Western Australia Geol. Survey Bull. No. 39*, Perth, 1910, p. 57.

[7] *Ibid.*, p. 81.

[8] E. g. Ellsworth Huntington: Civilization and Climate, New Haven, 1915.

Part II

The Climatic Control of Color and of Other Characteristics of Man

Before investigating the evolution of the human races, it seems advisable to discuss the importance of color as a factor in ethnological classification.

Race Divisions by Color

The early division of the human race into white, yellow, and black does not appear to be logical in view of the general distribution of the various peoples. As I shall indicate, the following order of colors fits the data better: chocolate, red-brown, brown, olive, and yellow (Table I and Pl. V).

The white races are numerically unimportant, as are also the true black races. The South Europeans are certainly not white, nor are most of the negroes black. We may add that none of the red Indians are red, while the Australian blackfellow is chocolate!

It is most probable that primitive man was very hairy, and the Batwa of Central Africa still bear the fetal lanugo. Their chocolate color developed in accord with their original environment, which has possibly been hot and moist from Pliocene times (when, as is shown later, they probably lived near Persia) down to the present (when they live in the African forests).

The Negro

The negro developed in a somewhat cooler climate, where, however, it was still hot. He lost some of the pigment and became a red-brown. When he migrated, if he reached hotter lands, he tended to become more tanned (i. e. blacker). This was largely for physiological reasons, for this enabled the sweat glands to act more efficiently and so perhaps keep the body cool. In West Africa and in Papua—both lying near the equator—he tends to become sooty, but elsewhere few negroes are really black. The dark migrants who live in cold climates (e. g. the Tasmanians) have not become white, because in my opinion they have not been there long enough to lose their original color. Most of their evolution occurred in the hotter moister regions far to the north.

The Hamitic Peoples

The Hamitic peoples, as I shall show, probably developed in a cooler region again, after the Ice Age. This type was greatly benefited by a somewhat more strenuous climate in the original Asiatic home. His brain increased notably and became more compact in its cranium. His pigment decreased on the average, and he became a brown color. This color also kept much the same as he migrated with the oncoming Ice Age, for he kept to the same climatic belt if possible. If he wandered long years in cooler

regions, as did the American Hurons, the color tended to become lighter, towards olive. If he lived for long years in arid regions, he would tend to become yellow. This may explain the Hottentot coloring, though the Hottentot is, of course, a hybrid.

The Olive Peoples

In the same way the olive peoples on occupying Europe found a cool moist climate, not at all similar to their original home. Here they became "bleached," as Sergi pointed out.[9] The numerous and important olive races of America have kept to a large extent their original color because their climate is as a whole very like that of their original home.

Half-Castes

The question of half-castes of course somewhat complicates the problem. But the very fact that there is such a regular progression in every direction along the continents, outward from the Asiatic center, as my main thesis shows, is enough to prove that the climatic "thrust" was the chief factor in producing the migration zones. They are not due merely to the interbreeding of dissimilar autochthonous races.

The tendency among savage races has usually been to prevent breeding with dissimilar races, and many primitive peoples prohibit it by elaborate systems of rules and taboos. The casual newcomer was killed; while, if numerous enough, the invading hordes pushed the weaker races before them.

Stature

The stature of peoples would seem to be largely a question of favorable environment. It is certainly true that city-dwellers are shorter than farming peoples and that ill-nourished folk are usually small. This no doubt largely explains the short stature of the Eskimos, the Bushmen, etc. It is often pointed out that the Scotch and the Patagonians are the tallest races. Most people do not realize that large areas in western Patagonia have much the same environment as Scotland. It is not certain that small stature is necessarily a primitive character. The Negritos are small, but they have usually had a hand-to-mouth existence. The Neandertal type was tall and, as I suggest later, may have preceded the Negrito in the scale of human development.

Infantile Characters

There seems to be a fruitful field for research in the study of the fetal and infantile characters of the races. I have referred to the lanugo. It is said that the black negroes are red-brown at birth (while the reverse has

[9] Giuseppe Sergi: Europa: l'Origine dei popoli europei e loro relazione coi popoli d'Africa, d'Asia e d'Oceania, Turin, 1908, pp. 258, 259.

been stated for northern Australia); that the yellow peoples are paler at birth; that the Tibetan children have chestnut hair until they are six years old. These and many other points require investigation.

No doubt the psychology of the races will afford valuable evidence. The childlike behavior of the negro has often been referred to as a primitive characteristic. The white races are versatile, gay, and inventive—all attributes of youth. The yellow peoples are grave, meditative, and melancholic—which possibly indicates their more mature position in the evolution of races.

Conclusion

For the above reasons it certainly seems wise to lay little stress on color and stature as guides to the evolution of the races. Anatomical features and hair texture and section would appear to be the least variable characters, and I have used these throughout my study of the migrations. The data are derived largely from Deniker's works,[10] especially as regards the cephalic indices.

Part III

Climatic Control of the Migrations of Man

Although the details of Tertiary geography are not well known, it seems certain that by Pliocene times the continents had much the same outline as at present. The chief differences were the greater extent of Europe in the North Sea region and in the Mediterranean region. The Red Sea was absent, and a broad gulf occupied the Ural region connecting the Arctic Ocean with the Caspian. The land surface of the East Indies and of New Zealand was much greater (see Fig. 8).

There were many more land bridges (or corridors, as I propose to call them) between the continents in past history, and this greatly modified the main lines of man's migrations.

Corridors and Migrations

The characteristics of a migration have always been much the same throughout the ages. A modern "migration," such as that of a city crowd to a football match, presents some useful analogies. First come the lowest classes and pariahs, who wander freely over the ground long before the general public arrives. They have arrived there by the usual roads and tracks but ultimately are found perched in tree tops and in the least attractive positions of the ground. Then the proletariat advances along the same

[10] E.g. Joseph Deniker: Les races et les peuples de la terre: Éléments d'anthropologie et d'ethnographie, Paris, 1900.

Idem: Les six races composant la population actuelle de l'Europe (Huxley Lecture for 1904), *Journ. Anthropol. Inst. of Great Britain and Ireland*, Vol. 34, 1904, pp. 181-206.

roads and corridors. They are driven out of the best seats, which are reserved for the last comers.

In the past history of man he has moved along the same corridors, which, as noted above, were often much broader than at present. Thus the Red Sea corridor was open for many of the migrations from Central Asia toward the southwest. Gibraltar was a very favorite corridor during the earlier migrations but broke down later on. Bering Sea is still very shallow and crossed by drowned ranges (e. g. Aleutian Isles). Probably this also was dry land.

We have evidence of the enormous extent of New Zealand in Tertiary times, for it stretched nearly up to New Guinea. The same story is true of Malaysia, where the Bali-Lombok strait seems to have separated two large lands in Tertiary times. The more southern was almost certainly joined to Australia at first. No doubt North and South America were united by a broad Antillean region.

Tertiary Conditions

All the data gathered in recent years go to show that Tertiary times were much longer than has been generally supposed. Twenty-five or thirty million years is a fairly reasonable estimate. So, also, the birth of man can justifiably be pushed back one or two million years; and this allows time for much greater changes in the continents during the human era than the early geologists had been willing to grant.

The chief differences, however, between modern times and middle Tertiary times were in the elevation and especially in the climate. The latter was much warmer, as noted earlier; for trees such as sassafras, which are characteristic of an isotherm of 65° or 80°, grew readily in France (which is now 55°). We may assume that the world isotherms as a whole were moved poleward in accord with this evidence.

The great mountains of the world to a large extent came into being toward the end of Tertiary time. Thus Central Asia, in place of being an arid plateau at an elevation of 10,000 feet, as now, was previously probably something like the Central States of the United States, with a corresponding improvement in rainfall and temperature. The Central Asiatic deserts are largely rain-shadow deserts due to the mountains and are not true trade-wind deserts, like most of the other large arid regions in warm climates.

The Anthropoids

Data are very scanty as regards the evolution of man's forerunners, the anthropoids. If we plot the occurrences of Tertiary fossils (following Matthew[11]) we shall surely obtain a clue as to the limits of the hot moist forests. The Eocene monkeys occur in the central United States and in France, which indicates that at that time these were tropical forests such as

[11] Matthew, *op. cit.*, Fig. 7 on p. 214.

those in which the lemurs live today. In Miocene times the forest belt has shrunk apparently, for the fossil anthropoids are found a little nearer the equator, in Italy, around the Aegean Sea, and in Persia (see Fig. 8).

When we reach Pliocene times the fossil anthropoids are still farther south and are found in northern India and in China. This may very well indicate the limit of the forested region of Pliocene times, though it is

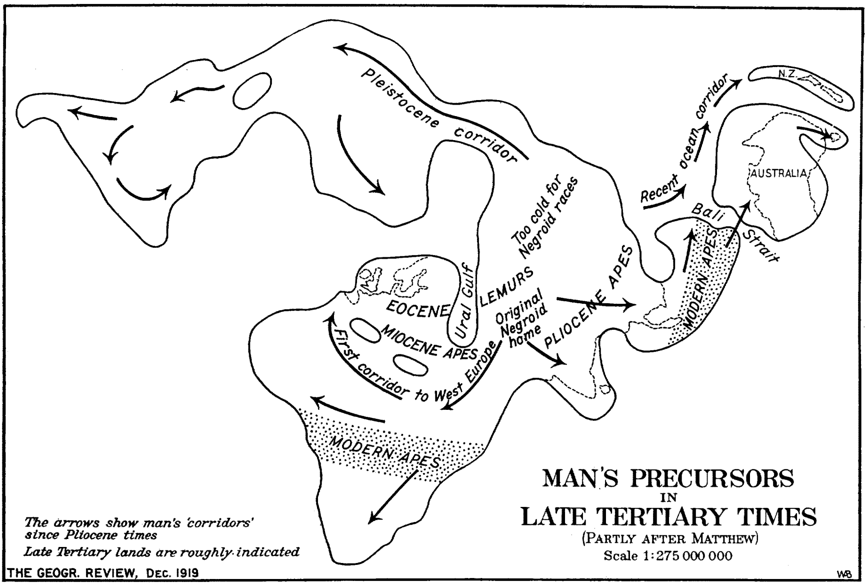

FIG. 8—Generalized map showing the distribution and migration routes of man's precursors in late Tertiary times (based partly on Fig. 7 in W. D. Matthew's "Climate and Evolution"). Scale, 1:275,000,000.

possible it was not as hot and moist there as in the regions where the apes are found today.

However, we are justified in assuming that the region between the Indian Ocean and the Aral Sea (Persia and Turkestan) was forested country with a warm moist climate. We know that the great plateau of Tibet and the Himalaya Mountains were not fully developed till the end of the Pliocene, and probably Asia as a whole was not much above sea level.

SEAT OF MAN'S ORIGIN

From the earlier discussion on Australian climates we may assume that a warming of the earth in these latitudes to 10° F. above its present state would suffice to shift the equatorial rain belt up to the Tropic of Cancer. A broad belt of well-watered forested country would extend north of this, and it is here that it seems likely that man originated. He would develop in the more open park-land country, where his loss of tail would be no handicap and where his powers of locomotion on the surface would be

exercised. Furthermore the more bracing climate on the polar side of the forest zone would make for energy and invention.

So far as we can reconstruct the isotherms these suggestions are permissible. The sea-level temperature of central Persia is about 75° now. If we imagine a rise of 10°, it becomes 85°. If we turn to Figure 2b we see that 85° agrees very well with the polar limit of the tropical rain belt.

With the equatorial rain belt so far to the north, the other belts would move north. The arid belt and polar rain belt would not, however, move so far away from present conditions as the tropical rain belt but would be "squeezed" against the central polar cold. (This is what occurs to some extent at present, for the tropical rain belt migrates much farther than, say, the isotherm of 32° F.)

It must not be supposed, however, that the equator was much hotter in the Pliocene. Probably it was even cooler than in the ice age periods. A redistribution of heat took place, as I shall show later, whereby the climates of the world as a whole alternated from uniform to zonal types.

We may therefore assume that the apes and pithecanthropoids followed the thick forests as they gradually retreated towards the equator. In Pliocene times we may picture the first man as a dweller on the edge of the forests—as are most of the primitive peoples of the world when left to their own devices (see Fig. 8).

Man's Primitive Character

Primitive man was no doubt more or less hairy all over his body and was probably below the present average stature and of a red-brown to black color. His skull was markedly dolichocephalic, and he had pronounced prognathism and black frizzy hair. (Throughout the following discussion consult Table I, p. 306, and Plate V.)

These features are all represented in the Batwa pygmies of Central Africa, who have been described from the region to the northwest of Victoria Nyanza. It is important to notice that here the climate is hot and moist, something like what we postulated for Central Asia in mid-Pliocene times.

Of the primitive characters specified above, the hairy covering is the first to disappear and is not present in allied tribes. The red-brown color is not very constant but depends on the climate. It tends to change to black in one direction and to yellow-brown in the other. The frizzy hair is very persistent, as are the other features. Stature probably varies greatly with environment and food available. In the case of hybrids the primitive hair seems to persist longer than the color, as we see in the Philippine Aeta and the Malay Sakai.

Relics of Primitive Man

With the onset of cooler conditions after the Pliocene, the ancestral home of man probably changed in character as much as any other portion of the

globe. For many thousand years early man wandered in small parties through southern Asia. He would be cut off from Europe by the Ural Sea and would have no reason to move into the more inclement regions to the north. Hence we should expect to find relics of this primitive type chiefly in Africa, in India, and in Australasia.

Here, indeed, is where they occur in the form of the Negritos of Central Africa, in the pygmies of the Andamans and Philippines, in the East Indies and in Papua, and formerly in Tasmania. (Since the Negritos have cephalic indices which range as widely as the Negroes, it is possible that the primitive Negro was co-eval with the Negrito rather than his descendant. But the Negrito in his other characteristics is much the more primitive.)

The Chellean Migration

Before considering the reason for this diversity of habitats, we must discuss the conditions in the Aralo-Persian region just before the First (Günz) Ice Age (cf. Fig. 9). Here a climate better suited for a virile race

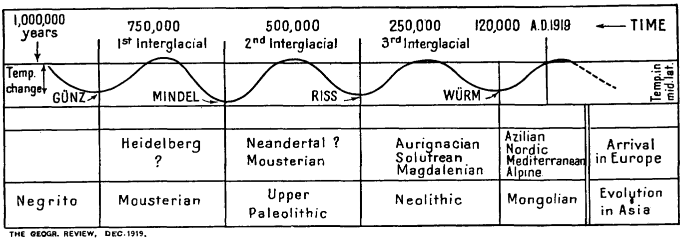

Fig. 9—Generalized diagram correlating the minor climatic cycles and ice ages with the human migrations from Asia to Europe.

had supervened. It was still warm, but not so wet as in the earlier Pliocene time. A race of taller dark dolichocephalic people developed. Their hair was still frizzy and was still flat in cross section.

During the early Pleistocene age—when the first of the great ice ages was commencing—they migrated from their homelands. Their routes were much the same corridors as those used by the Negrito. They drove the latter before them into the less pleasing portions of the world. This series of migrations included the earlier types of Negroes, of whom we find the chief representatives today in Papua and Melanesia and in southern and western Africa.

Some tribes of this migration seem to have reached Europe, probably by way of Morocco and Spain, and have left relics in the form of the early Chellean and Acheulian implements. The earliest skulls of Neandertal (and possibly of Piltdown) may well belong to this people. They have an oval head—much longer from forehead to occiput than from ear to ear—and hence are pronouncedly dolichocephalic.

When the early glacial ages were succeeded by a warm interglacial

period, these tall "longheads" penetrated into France and Britain, where they were contemporaneous with the mammoth.

We must, however, not imagine that all the Chellean people left southern Asia. There were fair lands far removed from the icy mountains of the center. Probably the regions of Persia and Turkestan were much more attractive at that period than they are now. The majority of the Chelleans would remain as near to their old home as possible, learning to overcome their environment, through the long period of the ensuing ice age.

We know that about this time the mammoth crossed the Bering region and entered North America. No doubt it was followed by a few of the outlying Chellean tribes, who slowly spread through the New World into the southern continent, though probably only in small numbers and at a much later date.

The Mousterian Migration

The next migration, thrust out by the Second Ice Age, was the "Mousterian." The Mousterians were also tall "longheads." They were much more expert workers in stone and had developed some primitive industries. They built shelter huts and were not unlike their direct descendants, the Australian aborigines.

It is difficult to decide whether the Australians were earlier or later than the true Negroes. The Veddah evidence would make them later than the Negro. Probably the Negro by stress of competition has developed his relatively high culture, while the isolated Australian has not altered from his original (late) Mousterian culture. In Perak the black Sakai are Negrito-Mongol hybrids. I find no record of true Negroes of the same "horizon" as the Bantu people in the migration toward Australia.

The hair is much less frizzled. It has become wavy or nearly straight and is oval in cross section. The face is still prognathous, the brow ridges are prominent, and the root of the nose is much depressed.

This Paleolithic race is well represented by weapons and skulls from Europe and North Africa, where it was the dominant race before the Hamitic-Iberian migration.

As with all the other primitive races it has been pushed back by the latest peoples. We find that the Mousterian Australian had displaced the Tasmanian. In southern India the late Mousterians are represented by the Veddahs and by some of the Dravidian tribes of the south. They have probably driven south the forerunners of the Nicobar and Andaman pygmies. Their characters and associates appear in the table.

In South America there is little doubt that, in the eastern Brazilian highlands, the Botocudo people are Mousterian. They have the same head index (73) as the Veddah and Australian and the same brow ridge and nasal depression. They build the same "wurley," or shelter, and wear no clothing. The ancient skulls, dug up at Lagoa Santa nearby, are even

TABLE I—MIGRATIONS OF THE HUMAN RACES, PLIOCENE TO RECENT

(Figures in table are cephalic indices)

RACE AND COLOR	AVERAGE CEPHALIC INDEX	AVERAGE ORBITAL INDEX	HAIR	HAIR SECTION	CULTURE	EUROPE	SOUTH AFRICA	NORTH AFRICA	AUSTRALIA	POLYNESIA	MALAYA	Caspian-Persian Region ORIGINAL HOME	INDIA	CHINA	EAST SIBERIA	NORTH AMERICA	SOUTH AMERICA
NEGRITO Chocolate to black	70 to 72	80 to 84	Frizzy	Flat	Acheulean ?	Too cold?	Hairy Batwa	(Dwarfs of Monuments and Somaliland)	Tasmanian hybrid 74	Fly River Papuan		Originated in Pliocene forests, possibly from Pithecanthropus type.	Mincopi, hybrid with Mongol ?	Aeta, hybrid with Mongol	Too cold	Too cold	
NEGRO Red-brown (Black in hot lands)	71 to 73	82 to 85	Frizzy to wavy	Flat to oval	Mousterian	Neandertal type arrived in early (2nd?) interglacial period	Early Bantu 71 Later 73	Early Wolof 69 Guinea Blacks	Australian aboriginal	Fijian hybrid 69 Melanesian 73	Mysore 70	Originated here in First Interglacial Period	Some Kol tribes Veddah		Eskimo hybrids ?	Calaveras skull ? Mousterian tools Greenland Eskimo hybrid 72	Bleached Botocudo and Caraya of Brazil (like Australian)
HAMITIC-IBERIAN Brown	73 to 76	84	Wavy	Flat to oval	Magdalenian Solutrean, Aurignacian	Aurignacian and Solutrean of Central Europe arrived in 3rd Interglacial. Some Portuguese	Aurignacian Bushmen (hybrid) and Hottentot Zulu	Fulah (hybrid) Moors		Moriori ?	Ceram 74	Originated here in Second Interglacial Period	Toda 74 Some Hindu	Some Lolo and Miao-tse	Bleached Ainu ?	Solutrean of California Eskimo Hurons	Solutrean in Argentina Some Brazilian tribes Cainguaetc.
EARLY ARYAN Olive-brown	76 to 78	86	Wavy	Oval	Late Neolithic Azilian	Arrived after Würm Age Azilian Bleached Nordics	Hova ?	Berbers Semite Arab	migrants	Moriori 76 Samoan Maori	Most Dyaks Sikai of Flores	Originated here in Third Interglacial Period	Bengal, Afghan	Moi in south	Ainu 75	Some Algonkians and early Californian	Some Carib tribes Yahgan
LATE ARYAN (SLAV etc.) Olive-white	78 to 82	87	Wavy to straight	Oval to round	Bronze European	Mediterranean races and some Central Europeans	later migrants	later migrants	later	later migrants	Javan Sumbawan	Originated after 4th Ice Age Persians 78	Some northern tribes	Japanese Korean North Chinese	Ostiaks	Zuñi Pawnee etc.	Yuracaré? Arawak Early Quechua
EARLY MONGOLIAN (TUNGUS) Pale yellow	82 to 86	90	Straight	Round	Sumerian *	Alpine races Magyar			No		Cambodian	Armenian Sumerian *		(Aeta hybrids	Tungus	Navajo Moki Yucatec	Some Quechua Araucanian
LATE MONGOLIAN (KIRGHIZ) Yellow	86 to 89		Straight	Round		Lapp	No	No		No	Burmese etc.	Kirghiz			Giliak	No later migrants	

* Sumerian culture—perhaps the first town life—was possibly early Mongolian. Thence it soon spread to Semitic people who had a happier environment and so progressed further.

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more primitive and represent earlier types of South American Mousterians. They are of lighter color for reasons suggested earlier.

In the later ice ages the climate of the center of migration in Asia was still cooler and moister. Under the influence of these controls the color of the remaining tribes became paler, changing from a red-brown or chocolate to a yellow-brown or tan color. The healthful energy-promoting climate led to a growth of civilization and intellect, which reacted on the cranium. The latter became much less oval (index 76) and more compact. The jaws decreased in size and projected less. The hair also lost its flat section and consequently did not wrinkle but was often wavy or nearly straight.

The Aurignacians

There seems to be a definite break here, between the Lower Paleolithic (Chellean, Mousterian) and Upper Paleolithic peoples, of whom the chief are the Aurignacian, Solutrean, and Magdalenian.

It seems logical to assume that the great change in culture is the outcome of a break in the continuity of descent. In fact we can with great reason place the Second Ice Age between the evolution of these peoples in Asia.

No doubt the early Paleolithic people marched south fleeing before the oncoming cold belts. Some hardier tribes withstood the environment better and reaped their reward in a more virile and intellectual posterity. These reoccupied the Central Asiatic region, on the retreat of the Mindel environment. Some hundreds of thousands of years later the oncoming adverse climate again drove most of these tribes to the south. They followed the old corridor into Africa and so arrived in western Europe in the Third Interglacial Period.

The chief characteristic of the earliest peoples in this migration was their artistic ability. The folk were oval-heads, dark brown or yellow-brown in color, and rather short. They were usually noted for their large buttocks, which are represented in many small models made by these Aurignacian peoples. The Bushmen of South Africa are hybrids who have preserved some of their characters, as Sollas has shown.[12]

Their drawings of reindeer and mammoth are found in the caves of southwestern Europe and could hardly be surpassed by modern draftsmen.

The Solutreans

They also were pushed away to the periphery of the lands in certain areas by a stronger later migration of a people known as Solutreans. Their representatives are found perhaps among the early Eskimos and allied tribes of the Arctic regions.

The characteristic laurel-leaf flints of Solutrean age are found in Argentina, California, and Mexico—where we should expect them, as a glance at the map (Pl. V) shows.

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[12] W. J. Sollas: Ancient Hunters and Their Modern Representatives, London, 1911, pp. 252-270.

Many of the later tribes of these peoples wandered into America via the Bering corridor. The Amerinds who now dwell in the northeast have cephalic indices about 76. Such tribes are the early Hurons and some of the Eskimos of Alaska. The short stature of the latter is probably a result of under-nourishment, as in so many other examples.

The Magdalenians

Professor Sollas compares the culture of the Eskimos with the prehistoric Magdalenian culture of France and Britain and shows the identity of many characteristics.[13]

The later peoples of this migration—or perhaps the earliest of the next—were the dark-brown races who are chiefly found in northwestern Africa and the western Mediterranean. They include the Iberians and other peoples who still occupy parts of Spain and Morocco. They seem to have entered Europe via the Gibraltar corridor. But later migrations crossed more directly from Asia to Europe; which may indicate when the Ural "gulf" became a feasible and broad land route. This is shown by the fact that the post-Iberian migrations have not driven the Iberians forward, but rather backward on their old track. This is, indeed, indicated in the map of the migration zones (Pl. V).

In India the dark-brown race with a cephalic index near 76 is represented by many tribes of the Deccan. In the mountain regions of southern China are the Lolo peoples, the Miao-tse, the Chiams, etc., who are of the same migration "horizon" as the Iberians and have certainly very little Mongolian blood in their veins. We know that they withstood the Chinese hordes for many centuries but were finally driven to the less attractive portions of China. Some of these tribes may, however, be a little higher in the ethnological record.

As the cycles advance we find the same general trend in evolution. The head becomes more compact, e. g. spherical, as the brain increases in size. Hence the cephalic index usually increases with the growth of culture. The hair becomes less frizzy and rounder in section. The eyes lie in rounder sockets (see orbital index in Table I). The color changes in a definite order, if we keep in mind the chief abiding place of the race in question.

The Aryan Migration

After the Second Glacial Age the early Neolithic peoples developed in the Aralo-Persian region and were driven south by the Riss glaciation. To this migration I have applied the somewhat ambiguous term "Aryan."

In Europe the migration seems to have included the earliest "Mediterranean" peoples, whose cephalic index was below 78.

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13 Sollas, *op. cit.*, pp. 348-350 and 368-383.

These people moved away under stress of hunger or occasional droughts and constituted the great Neolithic migration. They used polished stone weapons and erected large monoliths, which are scattered all over the world wherever their tribes migrated. These monuments occur very largely in Turkestan and southern Siberia, where the climate does not appear now to be suitable for a large population. They occur all through the north of Africa and through Persia. They are very common in northern India, Korea, Japan, and the East Indies. They are well-known features in North America and along the western coast as far as Chile. They are found even in the remote isles of Polynesia.

These Neolithic tribes followed the footsteps of more primitive peoples. They crossed into America by the same route, probably in the warm period of the Azilian age. It certainly seems more logical to assume an origin for the American Neolithic monuments similar to that of the Old World monuments and executed by allied people moving along the long-established migration route rather than to deny all connection because the links are not at present all complete. I shall return to this point later.

No doubt many of these Neolithic folk settled in large numbers along the eastern coast of Asia. They had a place in the ancestry of the Polynesians and in the Ainu, though the former have undoubtedly some later Mongolian blood also.

The Earliest "White" Races

As regards the central breeding place of the races, we have now reached the period just before the dawn of history. There is no doubt that the climate had become progressively drier in this region though not necessarily less healthy. Primitive irrigation would become a necessity of the settlers, who had taken to agricultural pursuits. This would stimulate invention and the growth of walled villages—just as was the case among the Pueblo Indians of America.

Under the stress of climatic impulse further migrants would wander away and settle in the nearest suitable regions. These wanderers of a pastoral type largely constitute the first so-called white races. Almost certainly they were more of an olive-brown, such as we see in the great majority of the Indo-Aryan races today.

They are found in northern India, in Arabia, and as scattered settlers throughout Burma and western China. Many of the Lolo peoples—the Moi tribes—and many others are fragments of migration of bearded white folk, which have been swamped by later yellow peoples.

In the south of South America it seems probable that the Yahgans are of somewhat similar origin though here the vast flood of later yellow folk has almost obliterated the earlier "white" migrants. However, some of the Tupi races in western Brazil have wavy and even frizzy hair, while the Yuracaré people of the Andes are "of very high stature, their skin being,

it is said, almost as white as that of a European.''[14] More data are required to establish this zone, however, in South America.

Nordic, Mediterranean, and Alpine Races

The Fourth Ice Age intervened between the birth of the Azilian, and perhaps of the Stone Monument, peoples and that of the group of people who are now the leaders in world civilization. These are the Nordic, Mediterranean, and Alpine races of Europe and the races akin to them on the same ethnographic horizon.

They all arrived in Europe long after the last (Würm) Ice Age—following far behind the Azilians on the return of the latter to the warming northern lands. They were of an olive color, much like the Greek and Spaniard, the Japanese and Northern Chinese, the Pawnee and Cheyenne Indians of today. All these, indeed, may be cousins and not so far removed from the Britisher as are the primitive Corsican and the Moor.

They followed the immemorial corridors and spread out all over the world, driving the Stone Monument peoples before them. Possibly the transition tribes were the Ainu and Nordics, who have many points in common with the Stone Monument people. All are characterized by long hair; and indeed the ancient Druids of Stonehenge and Brittany may serve as samples of this stage of human evolution.

Deniker states[15] that the extra (third) trochanter, or process on the thigh bone, and the adjacent fossa are characteristic of these people—i. e. the late polished-stone Belgians, the Ainu, and especially the Fuegians. (He does not, however, suggest their kinship on a common ethnological horizon, which seems to me obvious in view of their position.)

Relation of White and Yellow Races

The Ainu people are sufficient in themselves to disprove the fallacy that the white man is a cross between the yellow and black races. Where are the black races which are supposed to have mixed with the yellow to produce the Ainu, who, indeed, are not far from a typical Nordic people?

If the white man is developed from the yellow man, then logically the whole distribution of the races (as shown in the migration map, Pl. V) must equally indicate that the negro is developed from the white man!

As regards the status of the white and yellow races, it seems obvious that the Japanese and Northern Chinese are distant cousins of the chief peoples of Europe, i. e. those living between the Mediterranean and Nordic peoples. These pale-olive peoples of the East have of course some later Mongolian blood in them, as their lack of beard suggests. They are

14 Joseph Deniker: Les races et les peuples de la terre: Éléments d'anthropologie et d'ethnographie, Paris, 1900, p. 631. Cf. also L. E. Miller: The Yuracaré Indians of Eastern Bolivia, *Geogr. Rev.*, Vol. 4, 1917, pp. 450-464, especially pp. 450-451.

15 *Ibid.*, pp. 103-105.

apparently free from the dark Iberian blood with which the Europeans of the same horizon are usually endowed. Hence biologically the Japanese cannot be said to be inferior to the European.

Deniker says[16] of the Japanese: "The fine [i. e. higher] type . . . . . is characterized by a tall slim figure, a relative dolichocephaly, elongated face, straight eyes (in the men), ... thin, convex, or straight nose . . . . . . The color varies from pale yellow, almost white, to brownish yellow."

We must remember that the evolution of these races has extended through several hundred thousand years. The superiority or inferiority of a race as a whole cannot be determined by what has occurred in the last few hundred years. The idea of the superiority of the white race is natural in view of its present position. But we should remember that the belief was certainly not prevalent in the early Middle Ages, when Mongolian and even American civilization was practically on a level with ours.

Is it not possible that the Sumerian culture in Persia—perhaps the first true civilization—was due to early Mongolians? Petrie speaks[17] of the Sumerians as "shaven people," but the portraits have some appearance of the early Mongolian type.

Culture is largely a result of favorable environment; and by this time the early olive-white races had occupied the best regions and so ultimately developed the highest type of civilization. But they may have been taught by the Sumerian Mongol.

Polynesians and Americans

The Japanese peoples are said to have driven back the Ainu only so late as 600 B. C. No doubt the great Polynesian migrations date from somewhere about the same time. The Polynesians were pushed forth from the southeast of Asia long after navigation was understood. Many of the tribes in the Malay and Burmese regions are closely akin to the Polynesians, as are many of the Indonesian. Proximity to China has resulted in numerous migrations of brachycephalic Mongolians who have nearly swamped the olive peoples in many of the islands of Malaysia.

All round the American Andes we find peoples closely akin to these olive races of the Old World. Data are not readily obtained as to their ethnological coefficients, but we know that they have the olive color, the aquiline nose, and a similar high degree of intelligence. It is not difficult to connect the Indians of North and South America, for Deniker states[18] that the "Inca bone" of the cranium is found chiefly among the ancient Peruvians and the prehistoric dwellers of the Salt River Valley, Arizona,

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16 *Op. cit.*, pp. 450 and 451.

17 W. M. Flinders Petrie: Eastern Exploration, Past and Future (Lecture at the Royal Institution), London, 1918, p. 67.

18 Deniker, *op. cit.*, p. 79 (the latter reference based on Washington Gladden: Human Bones of the Hemenway Collection in the United States Army Medical Museum, *Memoirs Natl. Acad. of Sci.*, Vol. 6, pp. 139-286, Washington, D. C., 1893; reference on pp. 187-190).

showing their close affinity. It occurs also in some Europeans, and, though I have not seen the data, I expect that those with the same cephalic index (near 80) will be found to be the possessors of this link with the ancient

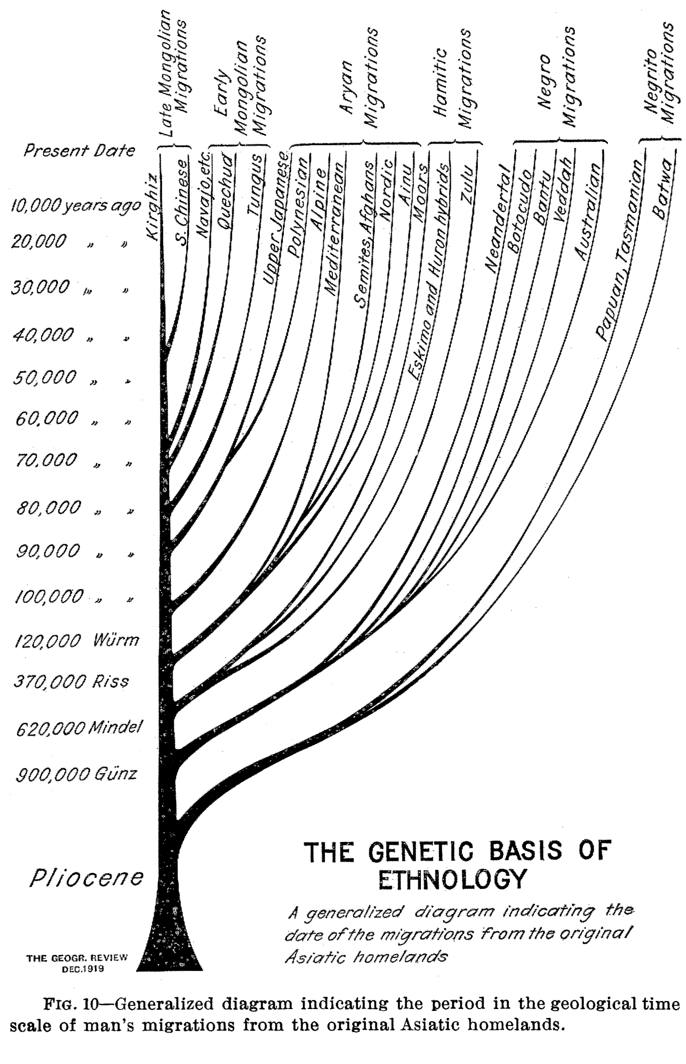
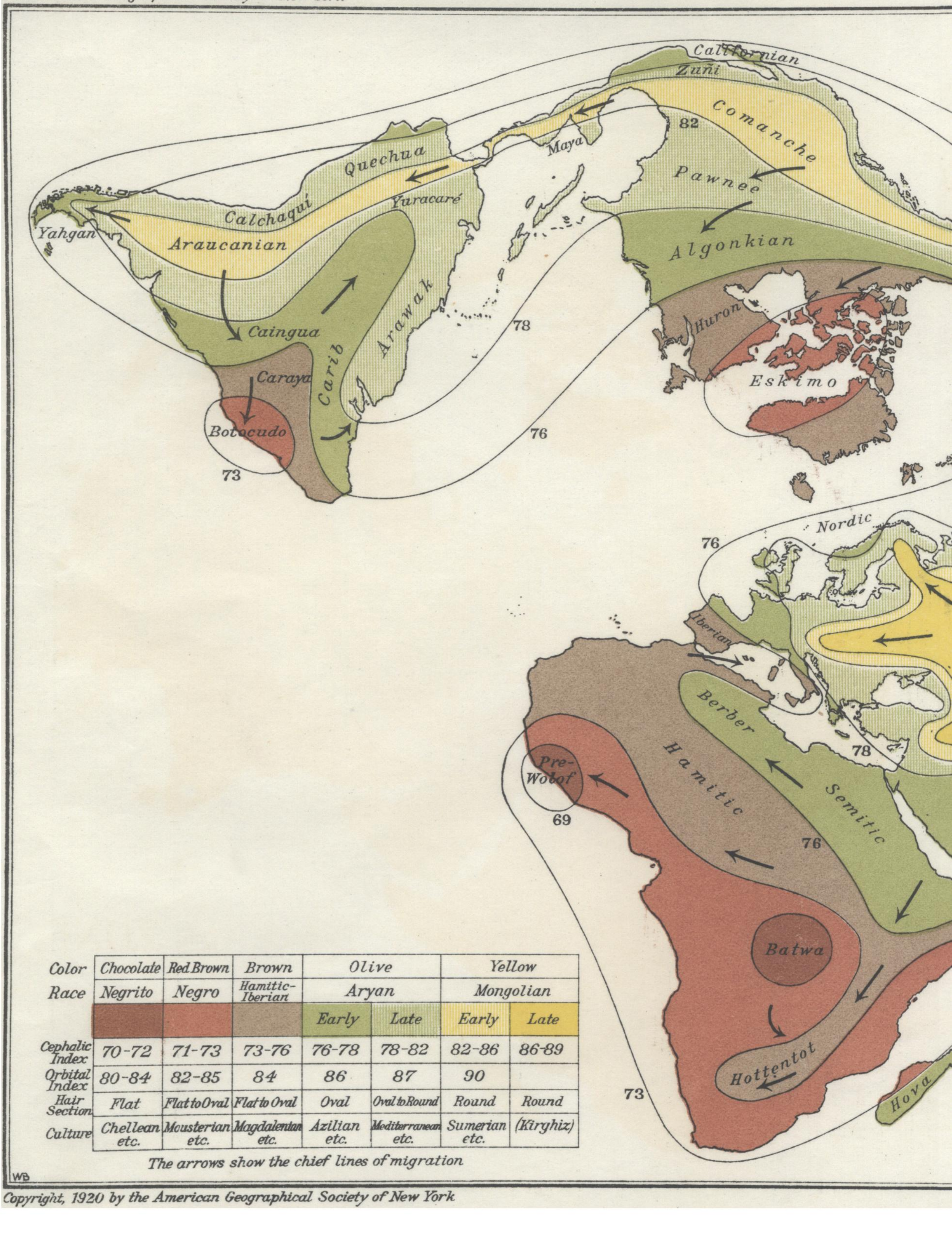


FIG. 10—Generalized diagram indicating the period in the geological time scale of man's migrations from the original Asiatic homelands.

Incas. An analogous distribution probably occurs with regard to the *Os japonicum* of the cheek, i. e. in the Japanese and their equivalents in Europe.

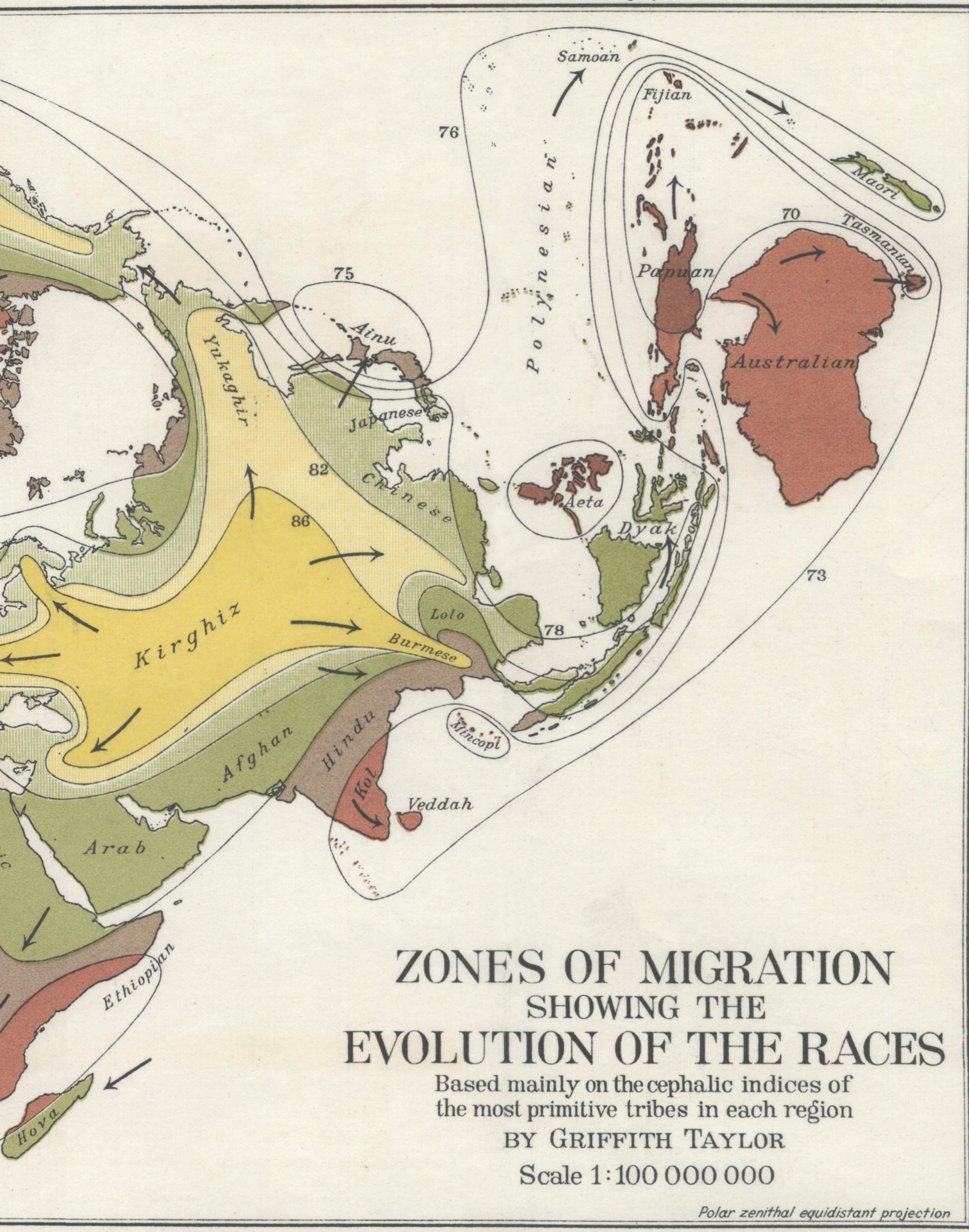
Later Migrations from Asia

We have now finished with the Pleistocene ice ages—for we are now living in the Fourth Interglacial Period.



Color	Chocolate	Red Brown	Brown	Olive		Yellow	
Race	Negrito	Negro	Hamitic-Iberian	Aryan		Mongolian	
				Early	Late	Early	Late
Cephalic Index	70-72	71-73	73-76	76-78	78-82	82-86	86-89
Orbital Index	80-84	82-85	84	86	87	90	
Hair Section	Flat	Flat to Oval	Flat to Oval	Oval	Oval to Round	Round	Round
Culture	Chellean etc.	Mousterian etc.	Magdalenian etc.	Azilian etc.	Mediterranean etc.	Sumerian etc.	(Kirghiz)

The arrows show the chief lines of migration



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But the climatic control does not therefore cease to cause migrations. It is, however, *drought* which has caused the later people of Asia to swarm forth from time to time. Huntington has investigated this question very carefully,[19] so that the "pulse of Asia" is now beyond doubt. This pulse was much weaker than the "thrusts" of the ice ages but operated in the same fashion.

Some great period of inclement climate in Central Asia drove out many of the early Asiatic peoples, and they appeared in Europe as the Alpine races and later as the Slavs. These arrived about the dawn of the historical period.

The Huns were true Mongolians, and the Magyars also have a cephalic index about 85 (see Table I). They spread through Europe (via the Urals) between 400 and 500 A. D. In the next century occurred the Avar migration, and in the sixth century that of the Bulgars. Many Slav people came in about 750 A. D., while Mongol Finns reached Flanders in 955.[20]

The African Semitic races made one or two migrations (probably as the result of "thrusts" on their eastern marches). Thus the Arabs reached Gibraltar in 710 and France in 730. A mixed race with some Semitic blood composed the Turkish invasion which approached Constantinople about 1000 A. D.

Early Mongolian Migrations to America

The last migrants to America were some of the earlier Mongols. Deniker states[21] that the Yukaghirs of Verkhoyansk approach very closely to certain northern Amerinds. They moved along the Rocky Mountains and the Andes as before. Down in the far south are the Tehuelches (index 85) with oblique eyes. Some of the Peruvian Quechua tribes are similar. So also are the people of Yucatan and many tribes allied to the Navajos. In all these cases crossing has hidden some of the characters, but the cephalic index always increases as we approach the great corridor of migration.

The British Columbian Indians may very likely be akin to an earlier migration, for their culture (e. g. carvings and canoes) has many affinities with the Maoris. I have no data of their coefficients.[22]

In Asia the Mongols burst through into India and founded the Mogul Empire in the seventeenth century. At a much earlier date, about 3000 B. C., the Mongols drove to the northeast the earlier people of China. This latest type of Mongolian "roundhead"—of whom the Kirghiz are a type—has never apparently reached America. Nor has their environment led them to develop any notable culture.

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[19] Ellsworth Huntington: The Pulse of Asia. Boston, 1907.

[20] W. M. Flinders Petrie: Migrations (The Huxley Lecture for 1906), *Journ. Anthropol. Inst. of Great Britain and Ireland*, Vol. 36, 1906, pp. 189-232; reference on p. 215.

[21] Deniker, *op. cit.*, pp. 431-432.

[22] On the map of North and South America showing cephalic index on p. 302 of Clark Wissler's "The American Indian," New York, 1917, the figures for the British Columbia area are 81 (Puget Sound), 80 (interior plateau: Thompson Indians?), and 83 (Alaska Panhandle: Tlingits).—Edit. Note.

Asiatic Invasions at the Present Time

Even at the present time the same Asiatic invasions occur. The Slav races are driving the Germans to the west, and partly in consequence the Germans were very largely settling in London before the war. The British again are emigrating before the economic pressure of the later races in central Europe.

It may be that the olive-white peoples with a cephalic index from 78 to 83 mark the zenith of the human race, but modern civilization has so short a history and is so obviously the product of a favorable environment that we have no right to assume so.

In Figure 10 I show how this charting of the migration zones affects the genetic "tree" of the human race. If it be accepted, then the accepted schemes of ethnographic classification will obviously need considerable modification.

Part IV

Climatic Cycles in the Geological Record

Temperature Changes in the Geological Past

It is clear from the earlier discussions that the north temperate zone (or mid-latitudes, as they are preferably described) was on the whole cooling during early Tertiary times.

With the Pleistocene we get the extraordinary oscillations in climate shown by the four ice ages and the three interglacial ages. If we take the present mean temperature of central Europe at about 50° F., then we may estimate the corresponding temperatures during earlier epochs as given in the following table. (The temperatures at latitude 30° N. and at the equator have been added for comparison.) These temperatures are based on paleobotanical and other evidence, but are, of course, only the roughest approximations.

TABLE II—Estimated Changes in Temperature, Present to Triassic
(In degrees Fahrenheit)

Age	Central Europe; Lat. 50° N.		Region of Ancient Civilizations: about Lat. 30° N.	Equator (suggested)
Present	50	(10° C.)	76	80
Historic	47		72	79
Neolithic	43		68	79
Würm Ice Age	40		65	82
Third Interglacial	52		76	80
Riss Ice Age	37		62	83
Second Interglacial	50		75	79
Mindel Ice Age	35	(Maximum zonal climatic type)	60	84
First Interglacial	52		76	79
Günz Ice Age	40		65	82
Pliocene	65	With some diminishing fluctuations corresponding to the Pleistocene cold periods	76	78
Miocene	70		76	77
Eocene	75		77	77
Cretaceous	76		77	77
Jurassic	76		77	77
Triassic	76	(Uniform climatic type)	77	77

The third column is in accord with the results of marine paleontology. Thus Smith writes[23] that during the Triassic there was "nearly uniform distribution of warm water over a part of the globe." Of the Jurassic Schuchert states[24] there was "a very wide medial warm-water area, embracing the present equatorial *and temperate zones,* with cooler *but not cold water* in polar areas." In the Lower Cretaceous we get some evidence of a *zonal* climate like the present, which did not last long, for the *uniform* climates held sway through Cretaceous and Eocene times (see Figs. 11 and 12).

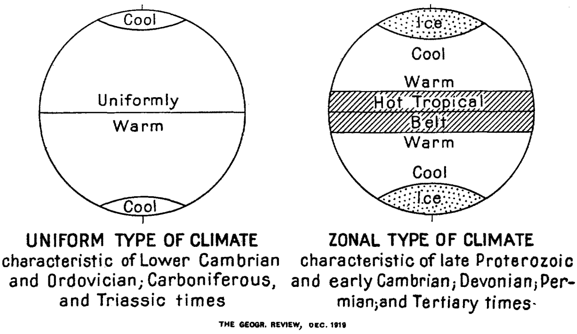

FIG. 11—Diagram illustrating the two types of temperature distribution, uniform and zonal.

It is in the Miocene, however, that the zonal type begins to predominate, and thence it continues to the present. In other words, in the early Tertiary we begin to see premonitions of the oncoming glacial periods in a series of fluctuations which gradually increase in intensity.

It is evident that we have here, but at a very much slower rate, a steady change of climate of the same type that we saw in Pleistocene and Recent times. Instead of alternations from cold to warm for mid-latitudes, we get a change from uniform to zonal which operates over the whole world, as is indisputably shown by the life record (see Fig. 12).

The growth rings of fossil plants corroborate this very remarkably, for they changed greatly in character during the last major cycle, as Schuchert reports.[25]

Pre-Tertiary Climatic Changes

I was therefore led to study the conditions of climatic changes in earlier geological periods (cf. Table III); and I found that the same sequence led up to the preceding ice age, that of the Permian.

David has shown[26] that there were three or four interglacials in the

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[23] J. P. Smith: Ancient Portals of the Earth, *Pop. Sci. Monthly,* Vol. 80, 1912, pp. 393-399; reference on p. 398.

[24] Charles Schuchert: Climates of Geologic Time, pp. 265-298 of Ellsworth Huntington's "The Climatic Factor as Illustrated in Arid America," *Carnegie Instn. Publ. No. 192,* Washington, D. C., 1914; reference on p. 281.

[25] *Ibid.,* p. 279.

[26] T. W. Edgeworth David *et al.:* The Geology of the Commonwealth, pp. 241-325 of "The Commonwealth of Australia: Federal Handbook Prepared in Connection with the Eighty-Fourth Meeting of the British Association for the Advancement of Science Held in Australia, August, 1914," Melbourne, (1914); reference on p. 274.

Permian glacial deposits of Australia. Hence the zonal climates occurred then exactly as in the Pleistocene and late Tertiary times.

In Carboniferous times we note exactly the same warming of the environment as we move further from the Permian. This is also coupled with the adoption of a uniform climate throughout most of the world. A cursory glance at Schuchert's masterly summary of past climates[27] will convince the student of the truth of this statement. He writes also:[28] "The world-

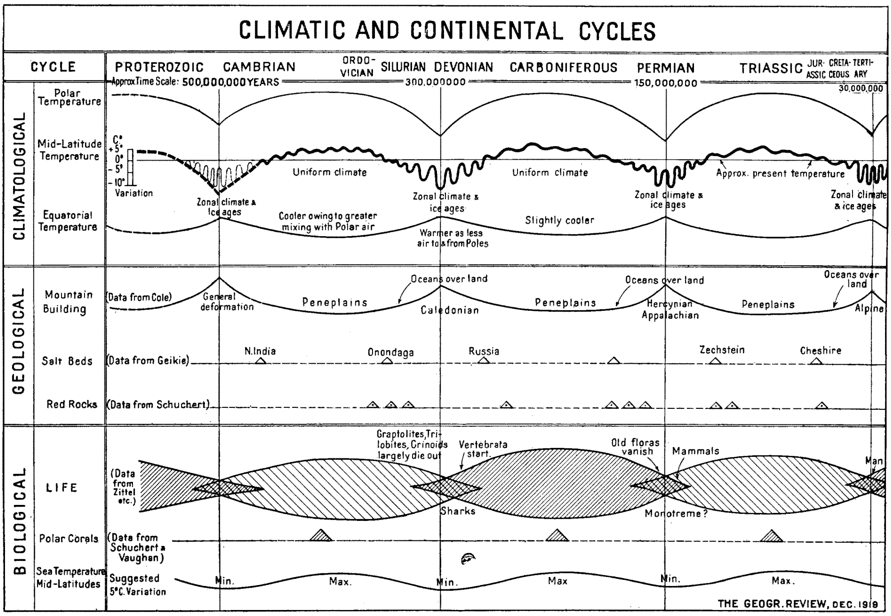

FIG. 12—Diagram showing the three major cycles in the climatological, geological, and biological records.

wide warm-water condition of the late Devonic seas of the northern hemisphere was continued into those of the Lower Carbonic." And, again:[29] "after middle Devonic times the climate of the world was as a rule uniformly warm and more or less humid and remained so to the close of Upper Carbonic time."

Let us now push our inquiry farther back again, using the same authoritative survey as our test. We get the same cycle of conditions.

"The temperatures of air and water had been mild to warm throughout the world since the beginning of Cambric time—there was a marked increase of warmth in the Upper Cambric, and these conditions were maintained through the Ordovicic and the earlier half of the Silurian."[30]

The Silurian closed with a period of zonal climates, culminating in an ice age, which has been recorded from South Africa. At Table Mountain (*fide* Schuchert[31]) are 5,000 feet of quartzites with striated pebbles up to 15 inches long.

27 Work cited in footnote 24. 28 p. 277. 29 p. 278. 30 pp. 276-277. 31 p. 269.

TABLE III—CYCLES IN THE GEOLOGICAL RECORD, FOR NORTH TEMPERATE LANDS CHIEFLY

(Quotations from Schuchert in "The Climatic Factor")

CYCLE		STAGE I Somewhat Zonal Climate Mountain Building Cool, but warmer than present	STAGE II Culmination Ice Ages and Interglacial Periods Mountain Building (Many genera die out) Colder than now, on whole	STAGE III Somewhat Zonal Climate at first Warm, drier	STAGE IV Uniform Climate Red Sands Salt Deposits Warmer, arid	STAGE V Culmination Uniform Climate Peneplains Warmer, moist	STAGE VI Uniform Climate Red Sands Salt Deposits Warm, arid
1st Cycle	RECENT		*Interglacial age*				
	PLEISTOCENE		*Four ice ages Man develops*				
	PLIOCENE						
	MIOCENE	*(Oaks in Spitsbergen)*					
	EOCENE	*Early cold cycle San Juan, Colo.*					
	CRETACEOUS	*"In N. Europe no warm seas" Mountains Sierra Nevada etc. uplifted*					*Red sands*
	JURASSIC						*"Cooler than Trias" Climatic zones begin*
	TRIASSIC				*Plants scarce (Upper) Red sands, Salt deposits New marine fauna (Lower)*	*Subtropical U.S. to Spitsbergen. (Nearly uniform warm water over globe)*	
	UPPER PERMIAN		*First land animals. Appalachian folding ends.*	*Vanishing swamps*			
	LOWER PERMIAN		*Great ice age {Urals? Australia S. Africa, India, Brazil*				
2nd Cycle	UPPER CARBONIFEROUS	*"Coolness and some glaciation" (Barrell) Appalachian folds start*					
	MIDDLE CARBONIFEROUS					*Warm in Spitsbergen Coal at Cape Lisburne, Alaska*	
	LOWER CARBONIFEROUS					*Warm seas and corals U.S. to Alaska*	
	UPPER DEVONIAN			*Increased "warmth in Upper Devonian" (Barrell) as compared with Lower Devonian*	*"Upper Devonian aridity" (Barrell)*	*Coal at Bear Island*	
	LOWER DEVONIAN		*(Old Red Sandstone glacial evidence in England?) "Entire stocks blotted out." Sharks and other Vertebrata start. Mountains and volcanoes in New England & Canada*				
3rd Cycle	UPPER SILURIAN	*"Caledonian Mountains"*	*5000 feet of glacial deposits in S. Africa harmonize with cold climate" (Barrell). Chiefly apparent in Southern Hemisphere.*				*Arid Climate*
	LOWER SILURIAN					*Mild and uniform climate "Warmer than Upper Silurian"*	
	ORDOVICIAN				*Mild and uniform climate. Red sands (Schuchert) Reef corals in North*		
	UPPER CAMBRIAN			*"Markedly warmer than Lower Cambrian"*	*"Lime habit" came in dominantly, suggestive of warm seas*		
	LOWER CAMBRIAN		*Some mountain building in E. America and W. Europe*				
4th	UPPER PROTEROZOIC	*Greatest ice age in the record! Australia; China, Norway etc Great mountain building.*					
5th	MIDDLE PROTEROZOIC	*Ice age of earlier cycle probable at Kadapah horizon, India, in Pretoria series, and Torridonian ?*					
6th	LOWER PROTEROZOIC	*" " " " " possible at Huronian level?*					

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It seems much more than a coincidence that this glacial epoch should be placed just here in the geological record. We must remember that the whole story of Cambrian and Permian ice ages is only a very few years old and that each year sees more and more evidence coming to light in support of their world-wide occurrence. No doubt the Devonian glaciation will be traced in many more regions in the near future.

If we go still farther back we get another great ice age, that of the late Proterozoic (or earliest Cambrian). This also fits into place in the cycles as far as we can judge from our knowledge of the time intervals since the Proterozoic. In the Proterozoic itself there are two early ice ages in all probability. These are indicated in Table III. No doubt they represent two earlier major cycles.

To sum up this aspect of the problem, we find that uniform climates govern the world for long periods of geological time. Then great disturbances ensue which give zonal climates of relatively short interval (say 200,000 years) which culminate in an ice age with marked interglacials. This type slowly passes away, and the world enters into its normal uniform climate again.

The zonal climates and great ice ages occur in late Proterozoic, Devonian, Permian, and late Tertiary times. The three periods of uniform climate occur in late Cambrian and Ordovician, in Carboniferous, and in Triassic times. The change from one to the other is, of course, gradual, as indicated on the graph (Fig. 12).

Periodicity of Warm Uniform Climates

This in itself is an important step to have taken in past climatology, but if we look more closely into the evidence we shall find that our study of Australian climatology will lead us much further.

We saw there that the desert belts migrated back and forth in the interglacial periods. Do they migrate in the oncoming and waning uniform period? There seems no doubt that they do. The zonal changes are passed through quickly but are of the same type as the vastly slower changes during the start and finish of the uniform climatic period.

If we take any given latitude belt, such as from 40° to 60° N., we shall find that it has been affected by the arid belt in greater or lesser degrees in past time. Thus Geikie gives[32] five notable horizons in which salt deposits and salt springs occur. These are the Lower Cambrian deposits of the Salt Range in India, the Onondaga salt beds of Canada, in the early Silurian; the Russian salt beds of the Upper Devonian; the Zechstein of the late Permian; and the Cheshire deposits of late Triassic (see Fig. 12). If we plot these on the graph we find that they occur midway between the ice age and the center of the uniform climate period in each of the cycles. Thus the north temperate lands passed from the cold wet periods of the

[32] Archibald Geikie: Text-book of Geology, London, 1882, pp. 661, 692, 704, 757, 759, 765.

ice ages, through the warm dry periods of the salt deposits, to the warm moister center of the uniform period; and so back through the dry period to the next ice age.

If we plot the red sands, as given by Schuchert[33], these arid deposits occur in almost the same periods as the salt (see the series of symbols in Fig. 12).

Let us now look at the presence of coral reefs in polar waters. Schuchert mentions[34] three notable examples. These occur in the Middle Ordovician from Alaska to Oklahoma, in the Lower Carboniferous, and again in Triassic times. No clearer proof is surely needed of the periodicity of warm uniform climates throughout the world (Fig. 12).

Testimony of the Biological Record

We must remember that at the present time land temperatures vary from +120° F. down to —90° F., a range of 210°. Sea water at the present time has a range from about +80° down to +28° F. At this lower temperature the pack ice effectively protects the water from the cold air, and the lower waters do not freeze. As a consequence polar seas are teeming with life. The floor of the Ross Sea is almost paved with siliceous sponges and swarms with shrimps and diatoms.[35] Hence we should not expect our climatic changes to have anything like so much effect on marine organisms as on land organisms—for the range is only 52° as opposed to 210° even in zonal periods. In the uniform periods probably the seas were almost the same temperature from equator to pole.

Let us now turn to the biological record (Fig. 12, bottom). There are four outstanding periods. The first is the dawn of the Cambrian, which for long years marked the oldest record of fossil life. We now know of many fossils in somewhat older rocks, but there is no doubt that some enormous change in environment affected life then.

At the close of the Silurian we have another critical stage. There were feeble precursors of the vertebrates before the Devonian, but the vast array of sharks and true vertebrate fishes commenced in the Devonian. Some great change blotted out all the graptolites, most of the trilobites, and many families of crinoids about that time also.

At the close of the Carboniferous the land floras changed remarkably, and we may with certainty follow Matthew[36] and place the birth of the mammals in the Permian. Now the first reptiles crawled on the land, and it is surely more than a coincidence that the primitive mammal (the platypus) still maintains his amphibian method of life.

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33 *Op. cit.*, pp. 273-274.

34 *Op. cit.*, p. 276 (based on T. W. Vaughan), 277, 280 (based on J. P. Smith).

35 See "With Scott: The Silver Lining" (1916), where I have discussed this question fairly fully (pp. 74-75 and 83).

36 Matthew: Climate and Evolution, p. 181.

The close of the Tertiary marks the culminating point in life—the dawn of the human age. No doubt the monkeys flourished in late Tertiary times, but it was the strenuous times of the Pleistocene which picked out the dominant type of mammal and gave to man the proud position which he occupies.

Surely these four stages, in agreement with the four zonal periods, indicate a cyclical type of evolution. The Cambrian is the dawn of an infinite number of new forms; the Devonian marks the birth of the vertebrates; the Permian the birth of the mammals; and the Pliocene and Pleistocene the birth of man.

Testimony of the Geological Record: Periodicity in Mountain Building and Vulcanicity

There remains one more cyclic phenomenon which I have not yet discussed. It has long been noted that the ice ages agreed with the periods of great mountain building (Fig. 12, middle).

If we study Cole's interesting account of the "Growth of Europe,"[37] we find that he specifies three main stages in the building of the continent. In late Silurian and early Devonian times occurred the great Caledonian uplift, which altered the whole shape of western Europe. In Permian times was the Hercynian period, when central Europe was puckered into great east-and-west folds. (This is the American Appalachian period.) In late Tertiary times we have the "Alpine storm," as he terms it, when the central portions of Europe were tossed like sea waves. This started at the end of Mesozoic times and culminated in Pliocene times, when all the great mountains of the world were raised to their present height.

Between these maxima—which coincide absolutely with the zonal-climate periods—there were stages of passivity. Great peneplanation occurred in the Ordovician, Carboniferous, and Triassic. Towards the close of these periods the first tremors of the zonal period were felt. As a result the seas largely invaded the flat continents, and we get the great transgression periods of the Silurian, early Permian, and Cretaceous. These also fit into the cyclic changes.

It would seem to me impossible to deny this periodicity, when the careful world surveys of so many investigators—Schuchert, Geikie, Cole, Zittel, and others—all point the same way.

It is not reasonable to expect every detail in the whole geological record to agree absolutely, for it is not suggested that no other factors operate beyond those here discussed. Vulcanicity is a test case. A world-wide survey will, I am sure, show some such arrangement as the following.

[37] Grenville A. J. Cole: The Growth of Europe (in series: The Home University Library of Modern Knowledge No. 84), London and New York, [1914].

TABLE IV—PERIODICITY IN MOUNTAIN BUILDING AND VULCANICITY

Periods of great mountain building and major vulcanicity (zonal type)	Late Proterozoic Early Cambrian	Late Silurian Devonian Early Carboniferous	Permian Early Triassic	Late Jurassic Cretaceous Tertiary
Periods of feeble mountain building and minor vulcanicity (uniform type)	Late Cambrian Ordovician Early Silurian	Middle and most of late Carboniferous	Triassic Early Jurassic	

But it is impossible to pick out one small country, such as England or Victoria, and judge by that alone.

A similar example of error from a limited survey would ensue if one were to study the climatic cycle during late Tertiary times merely as it occurred on the Sydney coast. Here the proximity to the sea and general onshore winds have probably given it a fairly uniform rainfall through late Tertiary times. We must study a continent as a whole, and then there is no doubt of the striking seasonal swing in one year or of the marked periodicity through long ages which I have tried to demonstrate in an earlier section.

If we study Australian igneous rocks[38]—as far as one can determine their ages—we find that they occur chiefly in the Pre-Cambrian, Cambrian, and Heathcotian (Cambrian?), that they are less important in the Ordovician and Silurian, and that they are very important in the Lower Devonian. The (Australian) New England and similar rocks may possibly be late Carboniferous; some are placed as Permian. The Triassic is poorly represented. The later Mesozoic and Tertiary agree with my hypothesis.

For Britain Geikie gives the following résumé.[39] Archean and Lower Cambrian show much vulcanicity (as also does Lower Silurian, which does not agree with the curve in Fig. 12). Then Lower Devonian was a time of prolonged activity, and early Carboniferous. Permian times witnessed many vents in Scotland. There were no outbursts in Triassic times; but, with the Tertiary, action begins again.

When we remember that it is very difficult to determine the age of igneous rocks, we may well consider that the relation of vulcanicity to zonal (disturbed) periods has been fairly brought out even in such a small region as Britain.

Part V

The Time Scale

Length of the Geological Periods

It is of course much easier to detect a period in a long lapse of time than to give the absolute value of such a period or cycle in years.

[38] Section on "Igneous Rocks" by T. W. Edgeworth David and E. W. Skeats (pp. 302-314) of work cited in footnote 26.

[39] Archibald Geikie: The Ancient Volcanoes of Great Britain, 2 vols., London, 1897, see Chapter 51.

Until recently geologists had no hope of determining the exact interval which had elapsed since the Proterozoic period. Stratigraphers have made many attempts and have divided the geological record into certain proportions. Thus the appendix to a popular article by Sollas[40] gives the tentative percentages listed in column A in the following table.

TABLE V—RELATIVE AND ABSOLUTE LENGTH OF THE GEOLOGICAL PERIODS

AGE	A (PER CENT)	B (PER CENT)	C (PER CENT)	D	E
Cambrian	16	16		500,000,000 years ago	300,000,000
Silurian	16	12	33	430,000,000 " "	
		5			
Devonian		5			
Carboniferous	35	20	33	370,000,000 years ago	150,000,000
Permian		8			
		3			
Mesozoic	25	25	34	30,000,000 (Eocene)	
Tertiary	8	6			
Total	100	100	100	500,000,000 years	300,000,000 years

A slight rearrangement—which can hardly be objected to as far as stratigraphy is concerned—would give us the ratios shown in column B. If these be subdivided in Devonian and Permian times—as the periodic graph demands (see Fig. 12)—then the agreement with the latter is absolute, and we have the geological record separated into three equal cycles by the Devonian and Permian epochs.

Holmes in 1913 in the "Age of the Earth" gives[41] the results of radioactive tests on the breaking down of various minerals. He would seem to favor 30,000,000 years (at least) for the Tertiary period and something over 430,000,000 years since the dawn of the Cambrian. Joly quotes[42] similar figures, indicating about 300,000,000 years as the time interval since the same epoch.

If we agree (as in column B) that the Tertiary occupied 6 per cent of the geological scale and that this is about 30,000,000 years, then the interval since the dawn of the Cambrian is from 300,000,000 to 500,000,000 years on all four scales in the table. This is perhaps as close an estimate as we can expect to make with the incomplete data at our disposal.

RELATIVE LENGTHS OF THE MINOR AND MAJOR CLIMATIC CYCLES

As regards the minor cycle (see Fig. 9), comprising the ice age between two interglacials, the evidence in the Pleistocene is somewhat better. In the Antarctic in 1911 we had a great deal of discussion on this very point,

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[40] W. J. Sollas in Harmsworth's "History of the World."

[41] Arthur Holmes: The Age of the Earth (in series: Harper's Library of Living Thought), London and New York, 1913, pp. 137-165.

[42] J. Joly: Radioactivity and Geology: An Account of Radioactive Energy on Terrestrial History, New York, 1909, pp. 227-230.

Idem: The Birth-Time of the World, and Other Scientific Essays, London, 1915, pp. 19-29.

when I instanced the graph given by Hess in his book on glaciers.[43] I describe this incident, which occurred when we were literally experiencing an ice age, in my book "With Scott: The Silver Lining."[44]

Later data (such as the chart given by Osborn[45]) seem to show that the Mindel-Riss Interglacial was the coldest and that the post-Riss period was warmer. Hence we have passed the culminating point. If the Pleistocene be taken as occupying 1,000,000 years, as Holmes suggests, then the four ice ages occurred at intervals of about 250,000 years. It follows that we may expect another cold period in about 100,000 years, though the indications are that it will be much milder than the Würm Ice Age.

It may be objected that Osborn does not place these epochs at equal intervals. On the other hand Hess does; and I incline to the latter view for the following reason. Nature in all her grander manifestations seems to be following cyclic laws. If we can detect the indication of a cycle with which many phenomena are in harmony, we shall be amply justified (by many similar discoveries in the past) in adopting the cycle as a most useful instrument for further investigation. As an illustration, I may add that I had realized the probability of interglacials in the Permian and had discussed it with a fellow geologist, who doubted the possibility of detecting them, before I found that Professor David had already described such.[46]

Thus the minor cycles are about 1/800 the length of the major cycles. From the fluctuations which are apparent in the Jurassic and Cretaceous, when colder conditions began to alternate with warmer uniform conditions, we may assume that these short-period cycles occur to a less marked degree in the periods between the major ice ages. In other words the minor cycle seems to be superimposed on the major cycle, but its amplitude increases as the major cycle culminates. However, this is all somewhat speculative and, like the succeeding sections, is only put forward as a suggestion.

Part VI

Suggestions as to the Causes of the Major and Minor Cycles

It has long been noted that mountain-building synchronized with the great ice ages. So far as I know no one has given a reason which explains both phenomena. The ice age does not directly depend on elevation, for the cold epoch affects lowlands also and sends great sheets of ice across the oceans.

I suggest that the common cause may be reached by way of a consideration of the circulation of the atmosphere.

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43 Hans Hess: Die Gletscher, Brunswick, 1904, p. 383.

44 pp. 280-281.

45 H. F. Osborn: Men of the Old Stone Age: Their Environment, Life, and Art, New York, 1916, p. 23.

46 T. W. Edgeworth David: Evidences of Glacial Action in Australia in Permo-Carboniferous Times, *Quart. Journ. Geol. Soc.*, Vol. 52, 1896, pp. 289-301.

Retardation of Earth's Rotation as Possible Cause, Producing Change in Atmospheric Circulation Resulting in Ice Ages

It will be admitted that high latitudes receive their meager supply of warmth chiefly by means of the poleward air currents. A striking example is seen in the North Atlantic, where the steady warm southwesterly winds and associated drift keep the sea open to Spitsbergen almost all the year round.

If this atmospheric circulation were increased we should get a much greater mixing of polar and equatorial air, and the whole earth would become of a much more uniform temperature. The ice caps would probably vanish; but in compensation the equator would probably be somewhat cooler than at present. This is exactly the condition which has obtained through the greater part of the geological record, as I have shown in an earlier section.

Now, what could cause the circulation of the atmosphere to change in character in this fashion? The simplest answer is to imagine a slight variation in the diurnal rotation of the earth. At present a spot on the equator moves round to the east at the rate of 1,037 miles an hour. As a result the pressure belts lie (in the southern hemisphere) about 35° S. (high pressure) and 65° S. (low pressure). If, however, the dynamic factor, which largely determines where they shall lie, is altered, their position will alter in accord.

If the rotation slightly decreases in velocity, then the belts will be less intense. Thus there will be less warm air driven to the pole and the temperature there will fall greatly. We shall thus tend to get the zonal type of climate, which we are experiencing at present. But a survey of past time shows us that a uniform distribution of heat has been more usual on the whole.

And Producing Crustal Stress and Mountain Building

As stated previously, there is a close connection between mountain building and the periods (late Proterozoic, Devonian, Permian, and Tertiary) when ice ages and the zonal climates obtained.

If the earth's rotation decreased slightly, the bulge at the equator would certainly tend to flatten out. The globe projects here about seven miles as a result of the present rotation of 1,037 miles an hour. I have no data from which to calculate the effect of a diminution of angular velocity of even one mile an hour on the shape of the earth. It is logical to assume that under such circumstances the lines of weakness would be affected by earthquakes and faulting, which, indeed, are prevalent in the present epoch. We should expect the less stable portions near the equator to collapse. There is evidence of this all through Tertiary times in the disappearance of the Antillean, Atlantean, and Malaysian continents. The temperate lands would buckle up—and we find that the major elevations

along the Tertiary mountain ranges are in such latitudes, e. g. the Titicaca and Tibetan plateaus.

That there has been a periodicity in the development of the continents is revealed by Professor Gregory's comments in "The Making of the Earth."[47] He writes: "In the Lower Ordovician an almost complete reversal of land and water occurred," as compared with the present condition. This is just what the present hypothesis demands, for the Lower Ordovician is one of the uniform periods, while the present is a zonal period. At that time North America and Asia were covered by the ocean, and a huge continent connected Africa with Australia and obliterated the Indian Ocean.

Of the next uniform period, i. e. the Carboniferous, Gregory states: "There is even clearer evidence of the recurrence of the Lower Ordovician arrangement, for a continent extended east and west across the southern hemisphere." This continent is known as Gondwana Land.

It seems evident that there is a sort of migration in the continents also. During the uniform periods equatorial lands appear to be very slowly built up, but these disintegrate rapidly (as ridges and fault blocks) during the zonal periods. This occurs especially along the equator, the lands "flowing" toward the higher latitudes. There is obviously much remaining to be explained which is not accounted for by any hypothesis to date.

Under these circumstances the most ancient relics of the crust might be expected to occur in its least disturbed portions. These would probably be in the region between latitudes 45° and 75°. At any rate here occur the chief coigns, or shields, of Archean age, which have remained more or less unaltered throughout the geological record.

It is to be noted that there are no southern lands corresponding to Canada, Russia, or Siberia, except perhaps Patagonia. Hence we are compelled to base our hypothesis almost entirely on northern hemisphere data, as far as these latitudes are concerned.

Explanation of Warming-Up After the Ice Ages

This suggestion—the retardation of the earth's rotation—gives no clue as to the warming-up which seems to follow the ice ages. Probably it is not a general warming so much as a redistribution of heat whereby the world slowly returns to the more normal uniform arrangement of temperature. If we can assume that the heat energy of the world is practically unaltered it may simplify the problem.

It does not seem possible that the earth's rotation accelerates again after the zonal period is over; though, as noted above, the equatorial lands seem to arise periodically. The initial rotation is determined by the conditions governing the birth of the planet, and almost all succeeding influences can only retard that rotation.

[47] J. W. Gregory: The Making of the Earth (in series: The Home University Library of Modern Knowledge No. 54), London and New York, 1912, p. 180.

It is to be noted, however, that the shrinkage of the earth's crust implies a greater speed of rotation (in accord with Kepler's Equal Area Law). Furthermore, we may note that it is possible that the radioactivity of the earth is gradually stimulated by the great deformations of zonal epochs and gradually heats the earth up to its average temperature.

Lest these suggestions appear too speculative, we must remember that the average decrease of terrestrial heat—whatever it may be—has resulted because all these factors have come into equilibrium in the course of aeons and aeons of earth history. The small interval of 300,000,000 years (which is all we have knowledge of in the fossil record) is insignificant compared with the whole life of our planet. Furthermore, we should remember that the maximum temperature change at any one place (at sea level) throughout the time we are considering is only about 15° Centigrade, which, again, is insignificant compared with the range of temperatures in the solar system.

Possible Astronomical Causes of the Earth's Retarded Rotation

What has caused the retardation of the earth, if such has occurred? It would seem to be due to a tidal action which operates in two cycles, one in every 200,000 years and another every 150,000,000 years. This may indicate stellar interference. I hesitate to make any suggestions—for

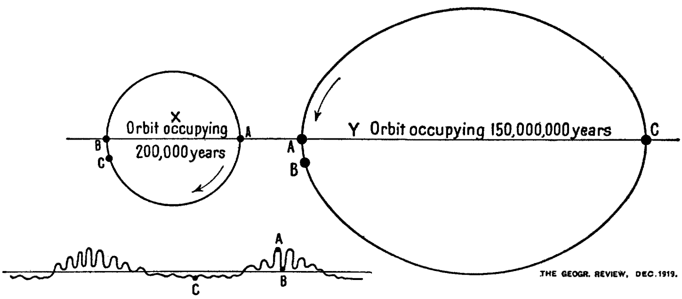

Fig. 13—Diagram illustrating the hypothetical interference of a stellar body Y upon a stellar body X, giving rise (in X) to the cyclic curve shown below to the left.

astronomy lies beyond the province of a physiographer, though it is necessary to include most sciences within the scope of his purview! However, the peculiar form of graph which I illustrate in Figure 13 would result if we assume the following conditions.

Let us imagine a planet or star, X, which has an orbit that it traverses in 200,000 years (see Fig. 13). Let us further postulate another infinitely greater star or planet, Y, with an orbit occupying 150,000,000 years. When Y is at its farthest point from the orbit of X, it will have very little effect on the latter. As Y comes nearer, its effect will grow more marked every 200,000 years as X swings past its "perigee." Finally, when X and Y are

at their nearest points of approach, both cycles of tidal action will be at their maximum. If we imagine that X corresponds to the solar system and that Y corresponds to some unknown star (now 100,000 years away from its nearest position to our system), my meaning may become plain.

It is usually assumed that the solar system is moving through space at the rate of about 11 miles a second. Some astronomers suggest, moreover, that the path is not straight but forms a closed orbit round the Pleiades. Whether this vast celestial revolution has any connection with the periodic cycles which I have endeavored to demonstrate in this paper is a problem which I leave in the hands of the astronomers.

Part VII

Summary

1. The world is at present passing through the Fourth Interglacial Period of the Pleistocene.

2. Temperatures as a whole are slightly warming, as if we had not yet reached the center of the Interglacial.

3. Hence the climatic belts are moving poleward from the equator. The desert region is encroaching on the southern coasts of Australia. The northern littoral is becoming wetter.

4. In the four ice ages of the Pleistocene the converse was true. The southern littoral was wetter than now, and the desert belt was nearer the equator. This ''swing'' occurs in the northern hemisphere also.

5. The control of historic civilization by the polar march of the belts is very marked, especially around the Mediterranean.

6. A survey of the effect on the Pleistocene history of man shows that there have been four great migrations (due to the four glacial ''thrusts'') from Central Asia, corresponding to the four earlier races of man—the Negrito, Negro, Hamitic-Iberian, Aryan.

7. These migrations all followed along the chief land routes, or ''corridors,'' and reached Africa and Europe, India, Malay-Australia, and America (e. g. Botocudo and Yahgan).

8. Traces of the Negroid migration are found in South America as well as in other ''peninsulas'' where they have been ''pushed to the wall'' by stronger and later races (e. g. Botocudo ''Australoids'').

9. The last (Würm) ice age thrust out the early Aryan races (olive) not only to India, Europe, and Africa but also into North China and Japan. A number of migrants reached America and are to be traced in the tribes of Brazil as well as in the Algonkians, etc., of North America.

10. Differences in color are connected with the climatic changes in the great Asiatic breeding place (Aralo-Persian region). The hot moist climates produced red-brown races; the cooler moist regions produced olive-brown races, the arid warm regions produced yellow peoples. These races all darken (tan) if they live long in a hot region and bleach (toward white) if they live long in a cold moist region.

11. The ancient cultures can be recognized all over the world and agree with the prehistoric evidence of western Europe and North Africa. Thus the migrations of the ''Stone Monument'' peoples are identified by the presence, in the skeletal remains of its

members, of an extra trochanter, or process on the thigh bone, in Belgium, Japan, and Patagonia.

12. It seems possible that the last typically yellow races were developed in an unfavorable region and are hence somewhat stunted. The upper-class (pale olive) peoples of China and Japan belong to the same migration as many Europeans. It is quite illogical to say the white man has developed from the yellow. One might just as well derive the negro from the white.

13. Turning now to earlier geological periods we find well-marked ice ages (before the Pleistocene) in the Permian and at the dawn of the Cambrian (late Proterozoic). There was also a third at the end of the Silurian. These four epochs are equidistant in the geological record (as far as evidence goes) and they are perhaps 100,000,000 years apart.

14. There is a well-marked alternation through the ages of periods with sharply differentiated climatic belts (*zonal*) and of periods with almost *uniform* climate throughout most of the world. We are living in a zonal period near the glacial culmination. Warm uniform climates occurred in Ordovician, Carboniferous, and Triassic.

15. The north temperate region passes through a cycle (each 100,000,000 years) from ice age to ice age as follows:

I. Cold wet ice age, mountain building, volcanic action, end of biological era. (There are probably interglacials as in Pleistocene.)
II. Warmer and drier, new genera in great numbers, some mountain building.
III. Warm arid, red sands, salt deposits.
IV. Uniform warm climate, coal and corals in polar regions, great peneplains.
V. Like III.
VI. Like II (except for life types).
VII. Like I; end of era.

16. In the Proterozoic we have evidence of two more cycles, probably of equal period.

17. The last ice age caused the development of man. The Permian is soon followed by the first mammals; the Silurian is followed by the first vertebrates; and the late Proterozoic by the well-known enormous increase in life.

18. As to the *causes of these cycles,* the following suggestions are made:

The alternation of zonal and uniform climates seems to be due to a decrease in the poleward flow of tropical air. This would follow on *retarded rotation* of the earth, for the dynamic circulation would decrease.

19. The coincidence of ice age and mountain building is very significant. The retarded rotation would cause the equatorial bulge to move poleward and induce great folding and volcanic action.

20. The change of the continents from equatorial to temperate belts seems to be indicated in the past record.

21. This theory gives no explanation for the increase in temperature after the ice ages. Possibly it is due to shrinkage in the crust (which would increase rotation), combined with increase in radioactivity (consequent on crumpling, etc.), so that a balance is arrived at not much, if any, colder than before the ice age. (Relatively minute temperature changes are all that is required.) The periodicity may indicate cosmic interference, no doubt affecting the sun also.